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ONE YEAR THREE FIFTY

GENERAL ELECTRIC

Review

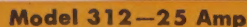
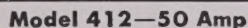
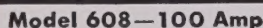
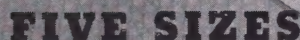
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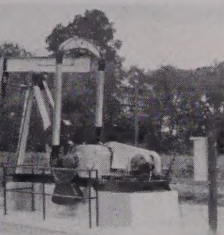
Industry's First Choice

GENERAL ELECTRIC

Review

SEPTEMBER, 1948

Vol. 51, No. 9



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Associate Editor

THE COVER

eam pumping equipment is used for about 90
ent of all pumped wells. Normally it operates
5 to 20 strokes per minute. Installations range
ize from about 3 to 75 horsepower, usually em-
ing a three-phase squirrel-cage induction motor
a pole-mounted outdoor control. This usually
udes a fused line switch, motor-starting mag-
c switch, control switch, undervoltage and tem-
ture overload protection, and sometimes auto-
ic time switch and lightning protector. Time-
operation can be prearranged for exact pump-
schedules. For further information on the use of
tric power in oil fields see p. 21.

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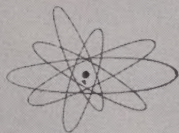
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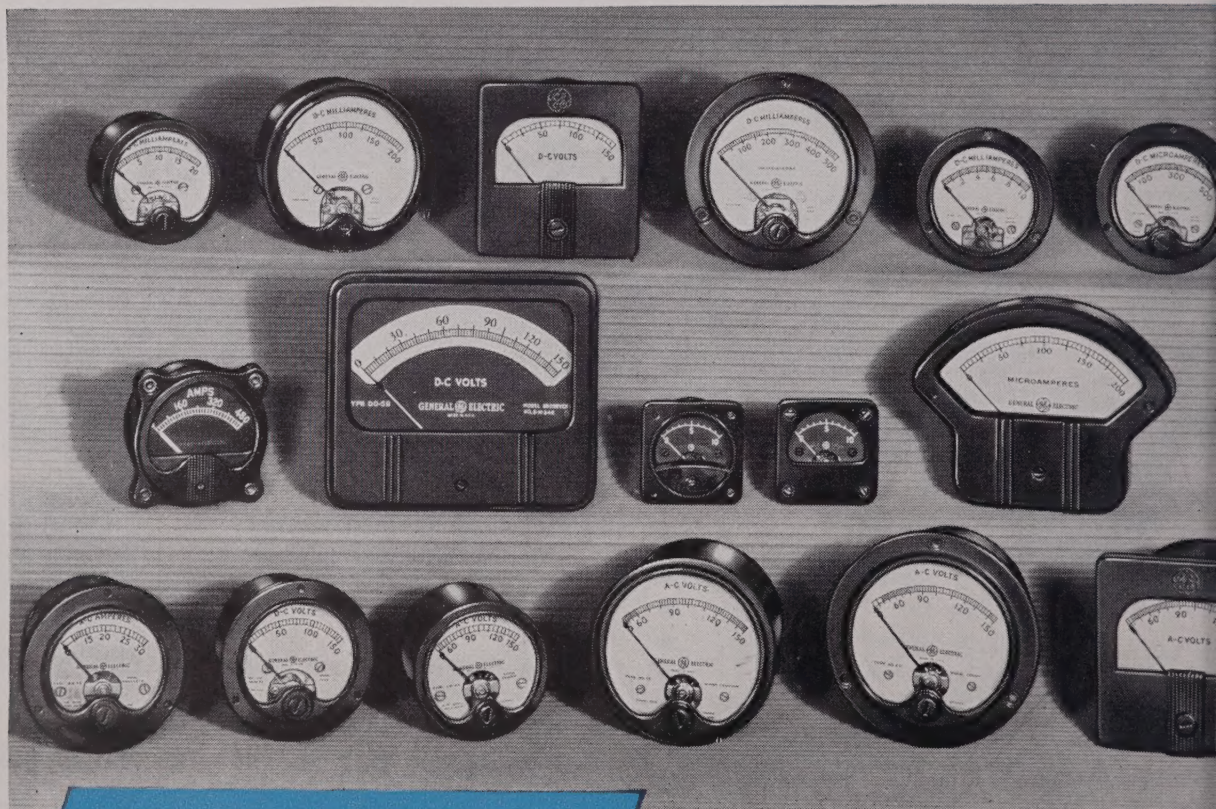
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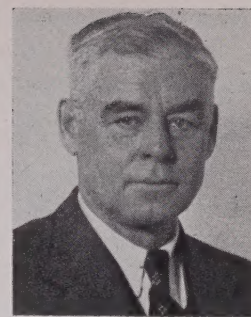
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GENERAL  ELECTRIC

POWER SYSTEM DESIGN CONCEPTS AND OPERATING PRACTICES

Some comments on trends of developments and on appropriate means of meeting modern technological and economic requirements

By D. M. JONES
Central Station Engineering Division
General Electric Company



D. M. Jones

MAN, in his long and persistent struggle for a better way of life, has attempted to meet his basic needs, in turn, by hunting; by tending his flocks; by tilling the soil to the sweat of his brow; and, finally, by devising machines to assist him in his endeavors.

Experience with these machines soon indicated the need for a suitable power supply to operate them; and due time engines appeared. A little later there was electric power, which, although initially hailed as a means for producing light, shortly took on as an ideal power supply for Man and his machines. Thus the Electric Companies initially were Lighting Companies, but the resulting increased availability of electric energy so stimulated Man's interest in his machines that the Industrial Era appeared; and this era, although in its infancy, has already given Man his highest standards of living.

With this experience behind him, Man is now imbued with the basic urge to continue this industrialization of his way of life with the hope of further improving his lot; and coincidentally, he also has begun to realize that such an advance must be based on a suitable supply of power. Consequently, the demand for electric power is now growing at a surprising rate. The pioneer Lighting Company therefore has now become a Power Company, and its physical plant, which once consisted of a generating station attached to an almost random jumble of lighting circuits, is now a Power System, with well recognized patterns of design, and highly developed practices of operation. But the end is not yet; for with this advancing Industrial Era the demand for electric power and the necessity for meeting that demand will continue to grow apace.

The resultant need for a sustained development of Power Systems plainly dictates a sound and comprehensive development of Power System design concepts, for in this field, as elsewhere, Man must project his understanding before he can intelligently proceed to accomplishment.

Power Systems Now Both a Technical and a Business Undertaking

With electric power now so intimately woven into advancing civilization, it is immediately apparent that these Power System concepts must include not only

the technical but also the economic aspects of the situation. It is no longer possible to support a given design arrangement as being competent simply because it is workable. It must be also economically justifiable.

The Power System Designer therefore now must be keenly alive to the technical and the business aspects of his problem. To meet this dual requirement, he now must both:

- (1). Take advantage of the most economic design concepts themselves; and
- (2). So execute them as to permit the use of preferred types and ratings of equipment.

Use of Preferred Types and Ratings

In support of the practicability of attaining the latter end is the general experience that, with any given design concept, the Power System costs, near the optimum, change but little with reasonable variation in the types and ratings of equipment used. Therefore the Power System Designer is free to execute over-all design concepts with sufficient flexibility to permit profiting from the lower price levels of preferred types and ratings of equipment without appreciable offsetting losses due to moderate departures from precise concept optimums.

This broad fact is the basis for much of the legitimate hope for lower Power System costs, because it points directly to the possibility of designing Power Systems in accordance with the most enlightened patterns, and still building them out of a relatively few types and ratings of unit devices; and these devices, in turn, then can be produced at lower cost levels through quantity production, either in toto or in terms of many of their component parts.

In order to make any appreciable progress in this direction, however, both system design and operating concepts, themselves, will have to be similar as between a majority of the Purchasers, for otherwise there will be no appreciable demand for common types and ratings of equipment, and therefore no quantity production.

Presented as a paper by the author at the AIEE Summer General Meeting, Mexico City, Mex., June 21-25, 1948.—Ed.

This article is so paged that, without mutilating other articles, it can be readily removed for filing as a group of full-size consecutive pages.—Ed.

On this basis, a discussion of Power System design and operation would appear to be justified:

(A). Trend to a Common Design Pattern

Electric Power Systems initially appeared in two divergent patterns. There were Power Systems with generation adjacent to the load; and there were Power Systems with generation more or less remote from the load. In the early stages of Power System development, these two patterns were fairly clearcut and distinctive.

In the first of those types, the generation commonly was from steam; and while there was a distribution system, there was no transmission. In the second type, the generation was usually from hydro; and transmission, as well as distribution, was a vital component of the Power System.

From the standpoint of the ultimate attainment of a common design concept, it is most fortunate that this early divergence in Power System design has largely disappeared through the combined pressure of the rising necessity for locating even steam generating plants remote from the load, and the growing realization of the practical and economic advantages of basic inter-connection both within and between Power Systems.

Therefore, all Power Systems now are converging on a common pattern which is based on a high-voltage-transmission backbone as the major integrating tie for the over-all system, supplemented by rational inter-connection with neighboring systems at transmission-voltage levels.

(B). Successive Stages in Power System Growth

Initially, however, Power Systems were relatively small affairs, serving more or less spot districts; but with time the rising demand for power caused them to enlarge their capacities, and their territories, and, therewith, the Expansion Period of their development was initiated.

In this period, transmission lines multiplied until they fairly webbed the districts which had begun to heed the call to industrialization; and so compelling was this urge to expand that lines commonly were built for immediate loads below the minimum for which they could be rationally designed, at the voltages considered advisable for the distances involved. Therefore, in this stage of Power System development, there normally was considerable excess capacity in transmission lines. Thus it was then common practice, even of remote power plants, to generate considerable reactive kva along with the kilowatts, and send them out together over the transmission lines as required by the load since, under the conditions, this could be done at almost no added investment except the minor increase in the price of the generators themselves occasioned by the resultant necessary enlargement of their field and armature ratings.

This System pattern was followed so generally in this Expansion Period that the standard hydro-

generator at that time was an 80-percent-power-factor machine; and the pattern was reasonably satisfactory as long as the need to carry maximum kilowatts over the lines had not yet appeared, and at the same time there was enough generation within the load area to provide acceptable general voltage control.

However, as this Expansion Period passed its zenith and the emphasis shifted from building lines primarily to cover new territory, to transmitting increasing amounts of power with a rising emphasis on economy, Power System design and operating concepts also began to change, as can be seen from the following:

(a). Analysis and experience alike ultimately indicated that the lowest-cost transmission at any given voltage could be obtained by designing and operating transmission lines at much heavier loads than were generally considered advisable prior to the operating experience of the War Emergency Period.

(b). To be able to handle such line loads on normal Power Systems with acceptable voltage conditions and stability margins, it proved necessary not only to primarily deliver kilowatts over those transmission lines, but also to furnish a fair amount of their normal (I^2X) excitation kva needs from the source generator, thus requiring their operation in the unity to 90-percent-power-factor over-excited range, and the remaining greater proportion of the line excitation kva from synchronous condensers at the load ends of the lines.

This new interest in line excitation kva stressed the over-all significance of reactive kva, and again pointed to the value of the present practice of considering the normal output of a Power System as consisting of two separate quantities, Kvar and Kilowatts; and reviewing generation, transmission, and distribution requirements and costs on this dual basis.

(c). This need for suitable stability margins on Power Systems with the heavier line loadings dictated by transmission economics re-emphasized the basic desirability of:

Intermediate switching stations on transmission lines to prevent excessive increases in circuit impedance incident to the clearing of faulted line sections;

Suitable breakers and relays for clearing such faulted line sections promptly and cleanly;

Proper co-ordination between circuit constants and generating equipment, both as to excitation and machine characteristics.

This includes the consideration that, for a hydro unit, the waterwheel output, under favorable hydraulic conditions, commonly exceeds its nameplate rating, thus indicating that the selection of the generator and step-up transformer ratings by simple reference to the waterwheel nameplate will result in over-all hydro-generating equipment with poor capacity co-ordination between its several parts.

(d). As a corollary to the effect of stability limitations on circuit design, it has been found that one of the most frequent errors in transmission circuit patterns is a tendency to carry the loop circuit, which admittedly has proved most useful at lower voltages, over into this higher-voltage field, where, because of increased loop length, the rise in circuit impedance, under the contingency of one end of the loop opening at the source, can be so great that the loop becomes inoperative. Such a loop, therefore, can be rated no better than a single source feed.

(e). With the development of Power Systems, practical operating experience has convincingly demonstrated that the Electric Power Supply for supporting this rising Industrial Age must meet certain reasonable basic requirements.

As Man and his Machines have come to depend more and more on Electric Power, it is self-evident that the quality of that commodity must be higher than when its contribution to Man's welfare was essentially limited to its ability to produce light, and the oil lamp or the candle was ready and waiting in the event of power outage, and even appreciable variations in voltage and frequency caused little criticism of this new and extraordinary light source.

Now, however, with the utilization of Electric Power so broadly developed, and the devices and appliances operating from it so numerous and so differently affected by variations in the Power Supply, it becomes evident that the Power Supply in turn must meet certain reasonable standards in such matters as reliability and constancy of voltage and frequency, to satisfy the rising needs of Society.

So, as the demand for Electric Energy grows, its quality must reasonably improve; and conversely, if its quality does not attain reasonable levels, its utilization, perforce, will be repressed; and thereby the economic advance of the dependent area will be severely hampered, if not entirely stifled.

Therefore, there are basic social requirements which call for the advancement of Power Systems along this broad road of rational evolutionary development, from an infant Lighting Company, through its adolescent period as an expanding Power Company, to ultimate attainment of the mature stature of a substantial, well-organized, and well-engineered business, where economy of performance and reasonable reliability and quality of product, are governing precepts.

Need for Progressing with System Design Patterns and Practices

With the path of development so clearly established by the basic requirements of the situation, it is both interesting and profitable to consider the effect of diligently progressing along this path, on the over-all economics of the Power System itself; and it is most encouraging to note how broadly beneficial this progress can be.

For example:

(1). In general, the costs of generation, distribution, and transmission of power decrease as the demand for it increases.

Large generating stations generally give lower unit costs than small ones.

Loaded distribution circuits give lower unit power carrying costs than empty ones.

Heavily loaded transmission lines lead to minimum transmission costs.

And even the normal increase in load-factor with the growth of System load reduces generation and delivery costs of electric power.

(2). Reasonable reliability of supply is an inherent by-product of sound Power System Design; and in addition, it is today's reasonable reliability that produces tomorrow's growth, and thereby assures a thriving enterprise for the future.

(3). As Power Systems grow, and also reasonably interconnect as required by economic and practical necessity, good frequency is an unavoidable attainment.

(4). When Power Systems attain their maturity; and transmission lines become loaded; and kilowatts, only, are transmitted; and the reactive kva for the load is produced as near to where it is needed as is feasible; it will be to the economic and practical advantage of the Power System, itself, to operate those transmission lines at essentially flat voltage throughout, so that all major transmission bus voltages will closely approach an equivalent common level.

This, of course, does not preclude the possibility that this common voltage level may be lowered at light load periods, if that be helpful in holding the system load voltages within the band of reasonable variation.

With this type of operation, the need for load-ratio control and even taps on major transformers is appreciably reduced, and correspondingly lower transformer costs result.

(5). Furthermore, the addition of intermediate switching stations and suitable fast breakers and fast relaying, for reasons already given, essentially eliminate excessive variations in these flat over-all system operating voltages, which makes it feasible to increasingly limit the transient overvoltages and profit by the resultant saving in insulation; in distinction to the older approach of accepting the overvoltages and providing the extra insulation required to meet them.

The following comments are in amplification of this basic statement:

It is now entirely feasible to eliminate lightning as a controlling factor in determining insulation requirements, through the use of line shielding, lower tower footing resistance, arresters, and associated approaches.

Likewise, the old lightning arrester now has become an overvoltage limiter, without reference to the source of the overvoltage, and in so doing has attained general industry acceptance as a means for limiting all transient overvoltages.

Therefore, it is now practicable to establish a maximum level for these transient overvoltages, as thus limited; and as the withstand strengths of insulation in general are also definable in terms of standard impulse tests, it is now possible to intelligently correlate the two and to select insulation levels on a rational engineering basis, once the ratings of the arresters are determined.

As choice of the arrester rating, in turn, is properly dictated by the maximum voltage at which it will be called upon to seal off the dynamic current following its operation on a transient overvoltage, the Power System design patterns outlined are most helpful in holding that choice to a low value, at any given System voltage level, and thereby in minimizing the transient overvoltages themselves.

TABLE I
TRANSMISSION COSTS AND LINE LOADINGS

Line Length (Miles)	Voltage (Kv)	Transmission Cost (mills per Kw-hr)		Line Load (Mva)
		Minimum Transformer Capacity	150 per cent Transformer Capacity	
50	161	0.58	0.83	160
	230	0.53	0.81	315
	287	0.54	0.87	475
	360	0.58	—	750
100	161	0.98	1.27	125
	230	0.85	1.16	220
	287	0.81	1.16	325
	360	0.86	1.38	460
600 50% Com- pensation	230	3.8	4.0	140
	287	3.3	3.7	215
	360	3.1	3.55	315
	450	3.2	4.1	515

This results from the consideration that, with a Power System design based on an integrating backbone transmission; and heavily loaded lines; and essentially flat voltages throughout; and adequate switching stations, so line faults can be cleared without loss of load or generation; as required on mature Power Systems, the range of operating voltages will be small, which, in turn, will permit lower arrester ratings; and lower arrester ratings in turn will hold the transient overvoltages to lower values.

This is in sharp contrast to what is attainable with arresters on Power Systems still operating in the expansion stage of their development, where the major lines have excessive voltage drops due to the transmission of considerable Kvar with the Kilowatts, and the lines have not yet been arranged for adequate switching and relaying; so that all too frequently, load, or generation, or both, are lost, with attendant excessive variations in operating voltage.

The rising economic advantage of holding the transient overvoltages to low values has also emphasized the general wisdom of operating transmission systems on a grounded basis. Therefore transmission lines, of 115 kv and above, normally are now operated with their neutrals solidly grounded; and the resulting use of lower rated arresters, in conjunction with proper system design concepts as outlined, justifies lower than present standard insulation levels, with attendant savings in

cost on both the transmission lines and their associated equipment.

In proceeding with this reduced-insulation approach, it of course will be necessary to provide sufficient creepage on exposed insulations to ensure successful operation.

(6). Then, too, there is the matter of the over-all effect of the economics of transmission itself, on Power System design and operating procedures.

The over-all cost of power transmission per kilowatt hour transmitted decreases as the transmission voltage increases, if there is enough power to be transmitted so that the lines can be designed for, and loaded to, their economic optimum without the resultant number of circuits being too few to meet the reliability requirements; and also provided the transmission voltage is held within certain maximum limits.

This maximum voltage limitation results from the transmission cost per unit of power transmitted, itself, following a diminishing-return law with rising transmission voltages, whereby it reaches a minimum value and then again increases with further advances in voltage. This is due to the increasing cost per kva of the associated transformers, with rising rated voltage, which in the range of 230 kv and above shortly becomes so pronounced that it overpowers the economic advantage of higher voltages on the lines themselves.

It will be apparent from the following data and remarks that the magnitude of this ceiling transmission voltage, as established by economics, also is much more nearly a fixed value throughout the whole practical range of transmission than commonly supposed, provided the optimum line loadings are acceptable.

The two outstanding variables in the transmission range, previously referred to, are of course, (A) distance; and (B) transformer capacity per line; and their influence on this maximum transmission voltage, therefore, suggests discussion.

(A). It is self-evident that distance is a basic variable in this situation.

(B). Variations in the transformer capacity per line are probable, due to the common experience that straightaway transmission often becomes essentially high-voltage distribution in a surprisingly short time, with the continued development of Power Systems;

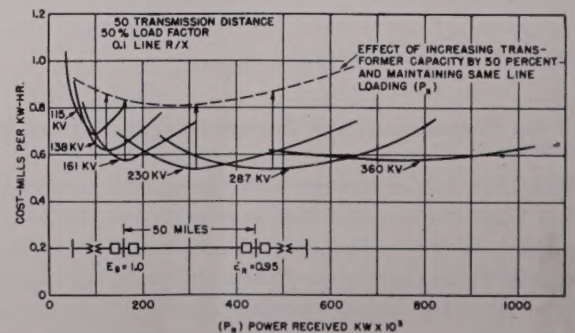


Fig. 1. Cost of transmission vs. power transmitted for 50-mile transmission distance

which, in turn, necessarily leads to a considerable increase in total transformer capacity per line.

If reference is now made to Figs. 1, 2 and 3, and Table I, certain facts are revealed:

These curves and data are based on the recent AIEE Paper "Economics of Long Distance A-C Power Transmission," by S. B. Cray and I. B. Johnson, and on subsequent similar studies, and therefore have been prepared with the full realization that, while increased distance has always been properly conquerable by increased voltage throughout our present transmission experience which reaches up to approximately 300 miles, this approach is no longer economically permissible as the distance exceeds this limit. Greater transmission distances can be most economically handled by reducing the equivalent electrical length of the line to within the 300-mile range in which we have been operating so far; and then, selecting the voltage, jointly in terms of basic transmission economics, and such practical matters as the rational loading per line, the number of lines required to give desired reliability, and the influence of the right-of-way factor on the situation.

Therefore, the comments on the 600-mile distance will be based on compensated lines only.

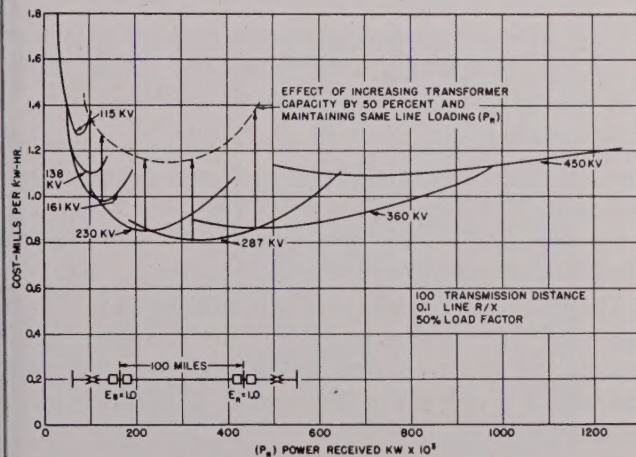


Fig. 2. Cost of transmission vs. power transmitted for 100-mile transmission distance

At 50 Miles (Fig. 1) the minimum transmission cost is at 230 kv; with 287 kv a very close second. When it is considered, however, that the corresponding line loadings are 315 mva and 475 mva respectively, it is evident that 230 kv is the more practical choice of the two.

Again, if the transformer capacity per line is increased 50 percent, the optimum voltage is decreased to about 10 percent below 230 kv; and the transmission cost at 287 kv becomes 0.06 mills higher instead of 0.01 mills higher than for 230 kv, which further supports 230 kv as the preferred level.

At 100 Miles (Fig. 2) the minimum transmission cost is at 287 kv, and is 0.04 mills lower than at 230 kv. The corresponding line loading also is sufficiently reduced so that the optimum load at 287 kv for 100 miles is essentially the same as at 230 kv for 50 miles.

Increasing the transformer capacity per line by 50 percent again reduces the optimum transmission voltage to about 10 per cent below 287 kv. This makes 230 kv and 287 kv a standoff as economic voltages.

At 600 Miles and 50 percent Compensation (Fig. 3) the minimum transmission cost of 3.1 mills at 360 kv increases to 3.3 mills at 287 kv; and to 3.2 mills at 450 kv. The line load at 360 kv of 315 mva is once more of the same order as the optimum cost loadings at 50 miles

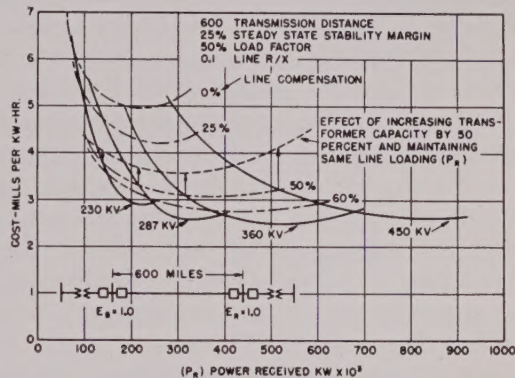


Fig. 3. Cost of transmission vs. power transmitted for 600-mile transmission distance

and 230 kv, and at 100 miles and 287 kv; and, while of major magnitude, will be feasible on the largest systems of the near future; but the 515 mva line loading at 450 kv, together with the evidence that the optimum voltage has been exceeded, throws out such a voltage under any conditions at present conceivable.

If the transformer capacity per line is increased, the economic distinction between 360 kv and 287 kv is reduced, but the spread in costs between 360 kv and 450 kv is considerably accentuated.

On this basis, any transmission arrangement, including compensation itself, which increases the transformer capacity per line will tend to better the relative economic position of 287 kv in comparison with 360 kv.

Fifty percent compensation may not give the ultimate minimum in transmission costs; but, as the percentage compensation is increased, the corresponding optimum line loadings become so much heavier that the higher compensation levels rapidly approach impracticability under any conditions now rationally conceivable.

Thus it is evident that the ceiling voltage, throughout the whole transmission range, consistently falls within the 230 kv to 360 kv band, and therefore precludes any requirement for still higher levels as far as one can now see. This termination of the rise in transmission voltages at the levels outlined indicates the possibility of meeting the ultimate equipment needs in this field with a minimum of voltages, and even without going beyond insulation levels already attained, if transient overvoltages are effectively controlled. Both of these possibilities, in turn, are favorable to reasonable equipment costs in this advanced transmission field.

But the existence of this maximum limit for transmission voltages, due to the nature of transmission economics, does dictate the eventual abandonment of the present general procedure for handling rising Power

System interrupting kva requirements. So far, whenever a Power System outgrew its existing pattern, as evidenced by such difficulties as abnormal transmission voltage drops and line losses, excessive interrupting requirements, and inadequate stability margins, a new and higher-voltage backbone transmission was superimposed on the existing transmission, which, in turn, was then sectionalized as required to restore acceptable operating conditions on it.

This generalized approach, to date, has proved so practical and so effective, and has seemed to be so continuously applicable with the sustained growth of the Power System, that the present levels of breaker interrupting capacities appeared to be entirely adequate for the future; for whenever these interrupting levels were about to be exceeded due to System growth, further increases in interrupting requirements not only could be halted by resorting to a higher backbone voltage as mentioned, but also this would be accompanied by a general improvement in transmission economy and operating performance.

It is now apparent, however, that when the maximum level of transmission voltage is reached, or even closely approached, this procedure of successively raising the system backbone voltage no longer can be invoked.

Therefore, when major system sectionalization at 230 kv recently was contemplated on the Bonneville Power Administration System for the basic purpose of holding the system interrupting capacity within the $3\frac{1}{2}$ million kva then listed as the maximum for such breakers, it was plainly evident to the Manufacturers that higher interrupting capacity breakers were needed. Fortunately, design and manufacturing understanding and capabilities were sufficiently advanced to justify considering as possible such larger interrupting capacity breakers, and therefore joint interrupting tests with the Reclamation Bureau and Bonneville Power Administration were instituted; and on the basis of the heartening assurance obtained from them, ten-million-kva interrupting capacity breakers are now in the process of manufacture; and at price levels which will result in appreciable over-all savings in Power System costs and in most acceptable improvements in operating simplicity.

This is further evidence that the necessary basic knowledge and ability for meeting the rising requirements of Power System Design continue to be available.

Conclusion

So, briefing the over-all situation just outlined, we have:

A rising demand for electric power as a basis for advancing our present way of life.

A growing realization that in order to fill such a vital position in our social order, Power System development both in the field of technology and economics, must be sustained activity, and the resulting power supply must attain reasonable performance levels.

An enlarging appreciation that this sustained development in both the technological and economic field does not basically conflict with the requirement that satisfactory service be rendered, if due advantage is taken of favorable design approaches.

The design approaches which offer the major economic possibilities can be grouped as follows:

- (1). The support of Quantity Production of equipment by the continued use of preferred types and ratings, with their more favorable price levels
- (2). The optimum loading of power lines
- (3). The active and intelligent prosecution of the concept of limiting overvoltages and using correspondingly less insulation on lines and equipment.

This hopeful view of the future is further supported by the consideration that the background knowledge and understanding in this field have now reached a stage where it is no longer necessary or advisable to proceed on the old trial-and-error basis.

Therefore, all experienced organizations in this field now regularly develop most carefully considered and analytically tested patterns for their future growth; and can readily demonstrate the economic advantage of so doing.

Thus those who have entered this Electric Power System field more recently are fortunate in the sense that they can proceed rapidly and confidently by profiting from what the Industry has learned so far.

Much of this accumulation of knowledge, of necessity, has been obtained the hard way in the past, by trial and error; but, having lived through that phase of the development, the Industry as a whole is now doubly conscious of the advantages of their present approach.

The resultant extraordinary development of the Electric Power Industry in the very short period it has existed is a fine example of the accomplishment which is possible in our modern way of life through the co-ordination of specialized intelligence, and we are very proud to have been permitted to make our proportional contribution to the present advanced status of this Industry, and trust we may be of equal service in the long period of development still ahead; for it has just begun to grow.

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DESIGN OF LARGE ELECTROMAGNETS

The features of construction, and the magnetic, electrical, and thermal factors. The higher the heat dissipation, the higher the allowable current density, and the higher the useful magnetic output for the same weight of coil

By MASON KRONICK

General Engineering and Consulting Laboratory
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Mason Kronick

IN PRESENT-DAY research in nuclear physics and other fields of science, the necessity for producing stronger and more uniform magnetic fields has been accentuated. This has resulted in the design of electromagnets of considerably larger sizes and of higher efficiencies than previously contemplated. Such an electromagnet is shown in Fig. 1.

The demand for intense fields, uniform over a large volume, or of a desired field gradient, has necessitated the extension of existing techniques in coil and magnet design, as well as the application of new ideas in which fuller utilization can be made of material and power

An extreme in the use of high current densities was probably achieved by Bitter⁽¹⁾. He was able to obtain extremely high flux densities over a small volume by the expedient of completely surrounding a small magnetizing coil with iron, except for suitable openings to permit access to the center of the coil where the field is produced. This required a very large power input and source of cooling, with a subsequent small amount of copper necessary for the field produced.

Conversely, when a large amount of copper is used, the power and cooling requirements are at a minimum. The problem is to effect a satisfactory compromise between the amount of initial material used and the requirements for power and cooling.

Iron Construction

The purpose of iron in a magnet is to provide a high-permeance path for the flux. Since iron may have a permeability as high as a thousand or more, up to a thousand times as much magnetomotive force (or ampere-turns) will be necessary to produce a flux through a length of air gap as would be required for the same length of iron.

Operating iron above its saturation point will cause unnecessary loss of magnetomotive force and will produce the same result as would be caused by increasing the length of the air gap. For good iron construction the cross section of the iron should be sufficient to cause the iron to operate at about the knee of its magnetization curve.

Excess iron cross section would result in operating the iron below the knee of the magnetization curve. Since the knee of the curve cannot be determined with exactness in terms of flux density or magnetomotive force, a certain latitude is available to the designer. He must make a compromise between the weight and cost of iron and the weight and cost of copper necessary to provide flux through that iron.

If there were no leakage, the designing would be straightforward. Because of the leakage flux, however, the total flux in the air gap (flux density times area of gap) is always less than the total flux of the yoke. By calculating the permeance of the various leakage paths one is able to determine the total flux in the various segments of the iron, such as the pole pieces, pole tips,

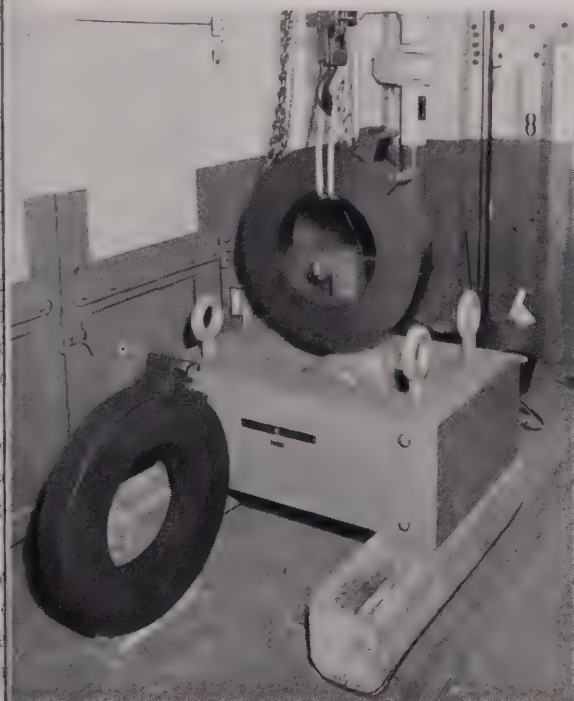


Fig. 1. Typical electromagnet shown with coils ready to be mounted on the yoke. The complete electromagnet weighs 12,000 lb

but. Designs for these large coils include new methods of winding and stacking conductors and insulators. By these methods, appreciably higher current densities can be used in water-cooled or oil-cooled coils, resulting in considerable savings in copper.

This article is so paged that, without mutilating other articles, it can be removed for filing as a group of full-size consecutive pages.—Ed.

(1) *Rev. Sci. Inst.*, vol. 7, Dec. 1936, p. 479; *ibid.*, vol. 8, Sept. 1937, p. 318.

yoke, legs, etc. The total flux will consequently determine the cross-sectional area of the iron for the desired flux density.

Determination of the permeance of the various leakage paths can be made either by the use of flux plots or by mathematical analysis. Reference may be made to Roters' *Electromagnet Devices* (John Wiley & Sons, Inc., 1941), Chapter 5, for some of the simpler equations for the calculation of permeance.

Procedure in Designing a Coil

After the number of ampere-turns necessary to produce the desired flux density in the air gap, and in the iron, has been established, the coils can be designed. The question then arises as to whether low current times large number of turns or high current times low number of turns is preferable.

Usually the latter combination is desirable. High current involves attainment of maximum current density without overheating the conductors. This is basically a problem of laying out the conductors and insulators so that the maximum amount of heat can be dissipated.

The usual procedure in coil designing is first to assume a current density, since this is the limiting condition. Knowing the desired ampere-turns, the voltage available, and the mean diameter of a turn, a wire size can be computed. Coupling this wire size with the assumed current density readily gives the current.

To determine whether the current density is too high for the shape and size of the coil, it is necessary first to calculate the wattage and then, by means of a thermal-flow diagram, determine the magnitude of the hot point of the coil. If this maximum temperature is within the allowable limit, then the wattage of the coil and the current density are not excessive. If the maximum temperature is excessive, a lower current density must be assumed and the calculations repeated.

Since the entire loss in a direct-current magnet is the I^2R loss in the coils, any means of dissipating the heat rapidly enough to allow high current values will increase the ratio of the magnetomotive force of the coils to the weight of the coils. In other words, the higher the heat dissipation, the higher the allowable current density; the higher the current density, the higher the useful magnetic output for the same weight of coil.

This can be shown as follows:

$$W = l \times A \times d$$

where W = weight of copper conductor

l = length of copper conductor

A = cross-sectional area of copper conductor

d = density of copper conductor

$$P = I^2 R = J^2 \times A^2 \times \frac{l}{A} \times \rho$$

where P = power

I = current

R = resistance

J = current density

ρ = resistivity

$$P = J^2 \rho \times A \times l = J^2 \rho \times V$$

where V = volume of copper

$$P = J^2 \rho \times W / d$$

It is therefore evident that, for a given power input, the weight of the copper used will vary inversely as the square of the current density.

This emphasizes the need to operate the coil at as high a current as the maximum allowable temperature will permit, and that in turn emphasizes the necessity of providing suitable means of conducting the heat away from the center of the coil.

For any contemplated design, the maximum allowable temperature will be dependent upon the insulation. This value of temperature coupled with the heat-dissipating ability of the coil will determine the allowable current density. Since density d is constant and the resistivity is constant at any one operating temperature, then at that temperature and at a current density J the power P is equal to the constant times the weight of the conductor.

The use of only paper insulation between turns in a coil allows a limiting temperature of 90 C, since paper falls in Class O of the AIEE Classification of Electric Insulation. If the paper is impregnated with permalite, the insulation can be considered Class A and a maximum temperature of 105 C is allowed. If fiber glass or similar inorganic materials are used, even with an organic binding material, the insulation may be considered Class B and a limiting insulation temperature of 130 C is assigned.

Fabrication

One method of designing a coil, which readily includes provision for the dissipation of heat, is the use of rows of copper ribbon between disks of copper tubing which are brazed water tubes. Insulation is used between the turns of ribbon and between the rows and the adjacent disks. The whole coil may be assembled in a tank by inserting individual rows or stacking separately. Another design method is to wind the copper ribbon on a cylinder and to use copper disks between the rows of stackings and for the coil walls.

Kraft paper of the same width as the copper ribbon can be used as insulation between turns. The paper is wound simultaneously with the ribbon. Large disks or washers of mica sheet form the insulation between the rows of stackings and the copper disks. Typical coil construction is shown in Fig. 2.

The conductors are interconnected at the top and bottom of alternate rows, so that by winding successive rows clockwise and then counterclockwise, the current is made to flow in the proper direction throughout the coil. This system necessitates the use of an even number of rows of conductors.

Copper tubing is brazed on the inside and outside peripheries of the copper disk to provide adequate heat transfer from the center of the coil to its outer surface. Fig. 3 shows such a disk; to this has been brazed the copper tubing through which cooling liquid flows.

The fabrication of the steel depends to a great extent upon the size of the magnet. For the smaller sizes of magnet, either cold-rolled or hot-rolled steel plate can be most efficiently used. Forgings or castings are usually chosen for the larger sizes, since final machining costs are thereby reduced.

In either case the magnetic properties should be investigated before selecting a material. It is the shape of the magnetization curve that is important to the designer. The steel that has the maximum saturation is not always the most desirable. More desirable is a steel of high permeability at the operating point.

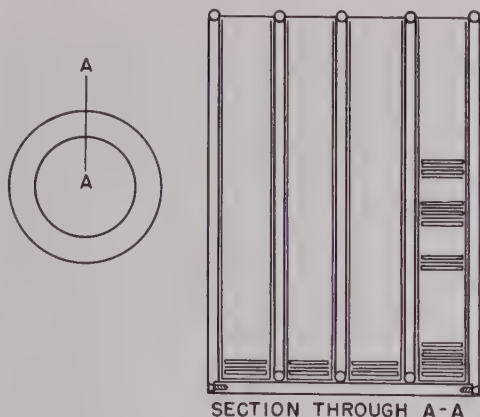


Fig. 2. Cross section of a coil similar to that in Fig. 1, showing four rows of conductor stackings including the necessary insulation and cooling disks

For the pole tips, where saturation is more likely to occur, an alloy steel—such as fifty-percent iron and fifty-percent cobalt—is sometimes used if the cost is justified.

For alternating-current electromagnets it is necessary that the magnetic structure consist of laminations rather than solid masses. This is necessary to minimize the losses due to eddy currents and hysteresis in the iron.

Thermal Problem

Until the designer acquires sufficient experience to assume the proper limiting value of current density, he should rely on calculations to determine the maximum ultimate temperature of the coil. This temperature will depend on the wattage input; on the size, shape, and material of the coil; and on the cooling system.

The temperature of a coil may be expressed by the formula

$$T = \frac{P}{K} \left(1 - e^{-\frac{K}{C}t} \right)$$

where T = average coil-temperature rise above ambient

P = power input

K = heat-dissipation capacity

C = thermal capacity of coil

t = time.

For t equal to infinity, the coil temperature T becomes P/K , and thus reaches a value directly proportional

to the power input and inversely proportional to the heat-dissipation capacity of the coil.

Actually, the time required to achieve this equilibrium value of temperature is some finite value dependent on the thermal capacity of the coil.

In the electromagnet application we are considering, it will be assumed that the period of operation is sustained, so that we can neglect the transient condition and can consider only the condition where $T = P/K$.

In an air-cooled coil, the heat-dissipation capacity is equal to the product of the heat-dissipation coefficient times the surface area of the coil times the temperature difference between the coil and the surrounding air.

For water-cooled coils there are no tables of heat-dissipation coefficient; therefore the solution for the maximum temperature becomes more complex. Usually a thermal-flow diagram is made.

Once an equilibrium temperature is reached in a coil, all the wattage input will manifest itself in a temperature rise of the coolant fluid. The higher the rate of flow of the coolant fluid, the lower the temperature rise. If the entire coil had the heat-conductivity properties of the copper winding, the temperature rise in the coil above that of the coolant would be small. However, because of the poor thermal properties of the insulating materials, the temperature rise in the coil may reach a dangerously high value.

By setting up a thermal circuit analogous to an electric circuit, with the source of heat as a "voltage," the temperature drop as a "resistance," and the flow of

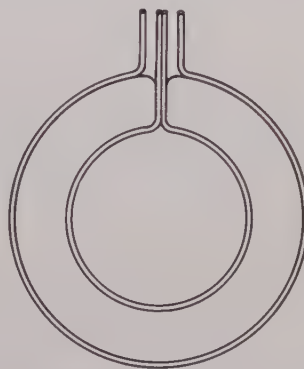


Fig. 3. Cooling disk, showing water tubing on the inside and outside peripheries

heat as a "current," one can readily solve for the unknown temperature. It is necessary to know only the thermal conductivities and dimensions of the coil materials in addition to the wattage of the coil.

The temperature drop across any element of a coil can be expressed by

$$T = q \times \frac{b}{k}$$

where T = temperature drop in deg C

q = watt/in.²

b = thickness of element in in.

k = thermal conductivity of element in watts/in.²/in./deg C.

For a single section of the coil, illustrated in **Fig. 4**, the analogous circuit shown in **Fig. 5** would indicate the thermal sources and sinks in the system. Solution of the equations obtained from the circuit would give the maximum temperature of the coil.

In the more complex coils, the thermal flow will be across many series and parallel paths. Such a condition usually necessitates several assumptions if a simple solution is to be reached. Regardless of the complexity

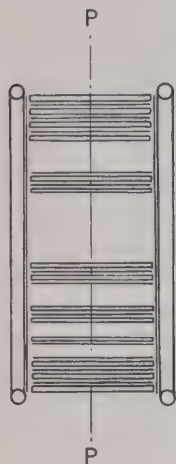


Fig. 4. Single section of an electromagnet coil, showing conductors, insulation, and cooling disks; also the plane of no heat flow for a single section

of the coil, it is ordinarily possible to establish a thermal-flow circuit of reasonable likeness to the actual flow of heat; thus a good approximation of the temperature of the coil can be computed.

Recent Examples of Large Electromagnet Design

The six-ton electromagnet (**Fig. 1**), recently built for Rutgers University, produced a field of 16,000 gauss across a 3½-in. gap with pole pieces of 19½-in. diameter.

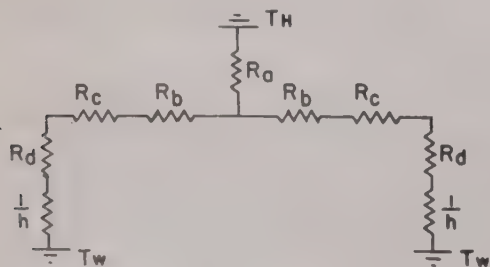


Fig. 5. Equivalent electric circuit analogous to the thermal circuit in the coil section shown in Fig. 4

- T_H = Temperature of hot point
- T_W = Temperature of coolant water
- h = Coefficient of surface-heat transfer between water and surface
- R = Thermal-resistance = Coefficient of thermal resistivity $\times$ thickness of material
- R_a = Thermal resistance of copper ribbon
- R_b = Thermal resistance of insulation (disks)
- R_c = Thermal resistance of air gap
- R_d = Thermal resistance of copper disks

For this flux density, the coils operated at a current density of 4000 amp per sq in., with the average temperature of the coils at about 80 C, while dissipating 39,000 watts. The hot point of the coils was about 95

C. To obtain a field of 15,000 gauss, a current of 132 amp (current density 3300 amp per sq in.) was passed through the 2000 turns. The average temperature of the coils was then 62 C, while dissipating 23,000 watts.

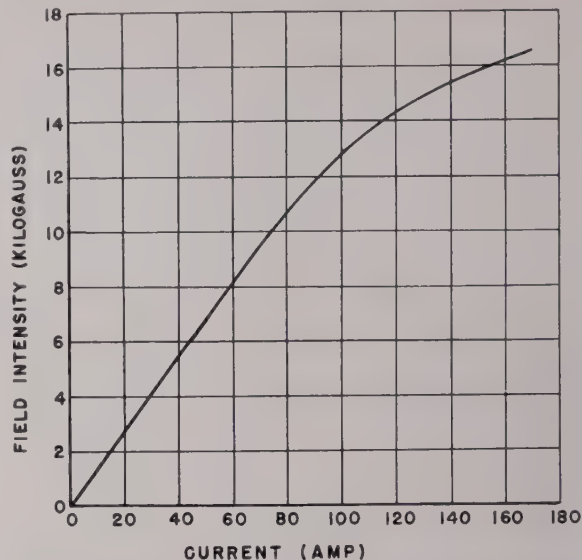


Fig. 6. Magnetization curve of the electromagnet shown in Fig. 1

Since 39,000 watts were necessary to produce a field of 16,000 gauss and only 23,000 watts for a field of 15,000 gauss, the optimum point of operation obviously lies somewhere between those two test points. Actu-

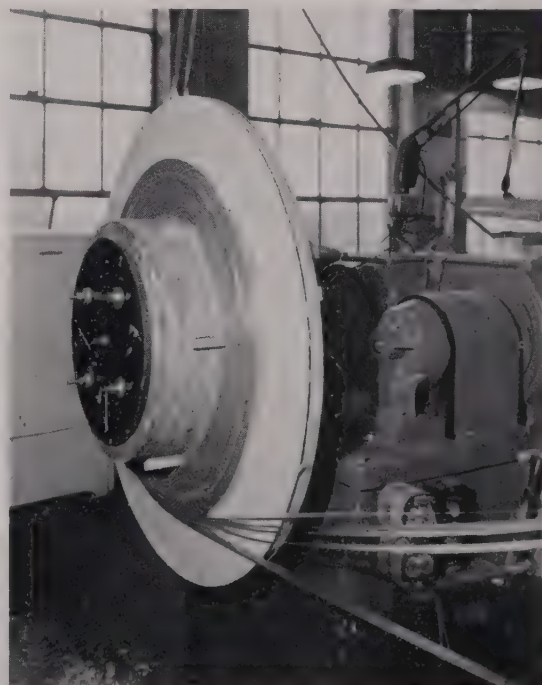


Fig. 7. Section of a cloud-chamber electromagnet coil on the winding machine

ally the magnet was designed for 15,000 gauss with a maximum current of 160 amp at 250 volts. The saturation curve of this electromagnet is shown in **Fig. 6**.

The electromagnet described here has copper disks between the rows of windings. Cooling tubes are brazed

on the outside periphery of all the disks and on the inside periphery of all but the outer disks. The latter omission was to aid in assembly of the coil.

Another design, this one for a cloud-chamber electromagnet (Figs. 7, 8, and 9) for the General Electric Research Laboratory, utilized water-cooled coils. Copper disks with water tubes on the inside and outside peripheries were placed alternately with the rows of windings in a large doughnut-shaped tank, which acts as a coil holder. In this way, extremely large coils too heavy to handle on a normal winding machine can be assembled in sections, each of which can be readily handled.



Fig. 8. Four sections and the cover of the cloud-chamber electromagnet coil before assembly

The important factor in either of these two designs is the inclusion of copper disks of large heat capacity for carrying the heat from the center of the coil to the water-cooled tubes. Although the disks add to the weight of the coils, they make possible a considerable

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reduction in the size of the coils by increasing the current density.

Experience has shown that the design of large electromagnets can be improved by the use of new ideas

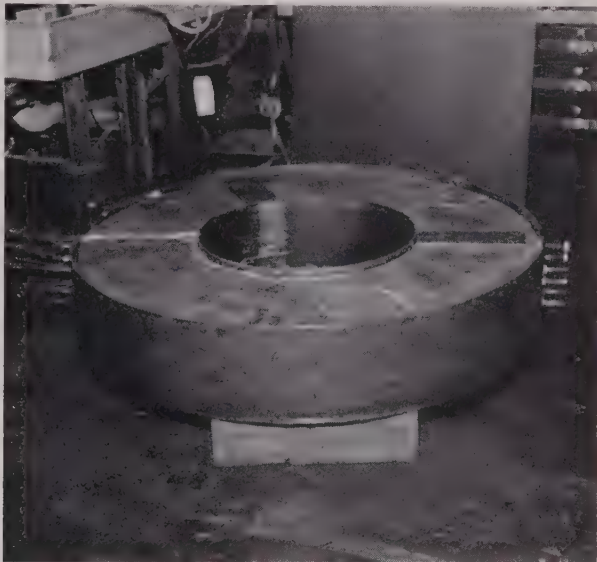


Fig. 9. Six-section coil assembled in its case for the cloud-chamber electromagnet

in coil cooling. These methods augment, rather than replace, the coil-cooling methods in which oil is circulated between conductors by means of spacers.

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OIL PRODUCTION BY ELECTRIC POWER

Description of the principal methods of operating producing wells, with pertinent comment upon the use of electric power and selection of equipment

By W. G. TAYLOR
Chemical and Petroleum Divisions
Industrial Engineering Divisions
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W. G. Taylor

IT IS well known in the oil industry that no two oil wells are alike. However, their operation in producing oil falls into certain definite patterns which simplify the design, selection, and use of mechanical and electric power equipment necessary to maintain the production throughout the useful life of each well. It is the purpose of this article to describe conditions affecting the application of electric power to the operation of producing oil wells, the selection of suitable electric equipment for this purpose, and the layout of electric power distribution systems in the oil fields.

Although oil wells drilled in a new field may flow naturally for a few weeks, months, or even years, from underground gas or water pressure, this pressure will eventually be dissipated to a point where oil flow will cease. Some artificial method of producing the oil must then be adopted. In the older oil fields, the underground reservoir pressure may already be largely exhausted, and new wells drilled in such fields require artificial production methods immediately. There are thousands of such wells drilled every year.

Most of the methods used to produce oil by application of power are included in the following list. Electric drive is applicable to all of them.

(1). *Beam pumping of individual wells.* About 90 percent of pumped wells are producing by this method, which employs a power-driven pumping unit incorporating a walking-beam to actuate a deep-well reciprocating pump by means of "sucker" rods.

(2). *Central-power pumping of wells in groups.* In this method, a central power-driven unit actuates pull rods extending to the wells to operate the deep-well pumps. This unit is usually called a "power."

(3). *Gas lift.* Natural gas, or sometimes air, delivered by power-driven compressors, blows the oil out of the well. The operation may be continuous or intermittent.

(4). *Centrifugal bottom-hole pumping.* This is exclusively an electrical application, using a submersible motor-driven centrifugal pump unit lowered into the well. This method sometimes has been combined with gas lift, to pump oil part way up the hole and then blow it out the rest of the way.

(5). *Hydraulic pumping.* The deep-well reciprocating pump is actuated by oil under pressure, which is delivered down the hole by a power-driven pump at the surface.

(6). *Plunger lift.* A free-traveling plunger actuated by gas pressure lifts the oil by moving the entire length of the tubing from the foot-piece to the flow-head at the surface. The gas is delivered from power-driven compressors.

(7). *Pneumatic rod lift.* The rods connected to the deep-well pump are raised and lowered by an air-actuated piston in a cylinder at the surface. Power-driven air compressors supply the air.

(8). *Casing rod pumping.* In this method, the reciprocating deep-well pump, fixed in the casing at the bottom of the well and actuated by sucker rods from a pumping unit at the surface, delivers the oil up through the casing without the use of tubing.

(9). *Swabbing.* The oil is produced by a swab which is raised and lowered in the well casing by a power-driven hoist. This method is employed for production only temporarily or in special cases.

(10). *Repressuring.* This is an indirect method of production by prolonging the natural flow of wells. Natural gas is forced into the oil-bearing formation by power-driven compressors, to maintain sufficient underground reservoir pressure for the wells to continue flowing.

Table I shows the approximate limitations of each of these methods of production from the standpoint of depth of well and amount of production, and the approximate range of horsepower requirements. The application of electric drive to methods (1) to (5) inclusive will be discussed in this article, since they are employed in many oil fields. The other methods except repressuring (10) are not extensively used and will not be considered further. Some additional comments will be given on repressuring, however.

Control of Production from Flowing Wells

By means of automatic electric control, the flow of each individual well in a group of flowing wells on a property can be accurately timed in accordance with proration or other requirements. The flowing period each day can be scheduled progressively, simultaneously, or with any desired overlapping. The lease

This article is the descriptive portion of a paper presented at the AIEE Summer General Meeting at Mexico City, Mexico, June 21-25, 1948.—Ed.

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tanks can be filled consecutively or in the order of their emptying. When all tanks are filled, the flow stops automatically until a tank is again available. When a day's production quota is met, the oil flow is stopped until the next day, when it is resumed automatically on the same schedule.

Such operation is accomplished by a time switch on each well, controlling electrically operated and interlocked valves. A master timer starts and stops the daily program, and temporarily stops all scheduled operations if an emergency arises. All operations can be automatically recorded.

Beam Pumping

Beam pumping uses a single-acting reciprocating pump located in the well. In its simplest form (Fig. 1) it consists of a working barrel with a valved plunger. The working barrel is attached to the lower end of a string of tubing. The plunger is suspended from a string of sucker rods which is hung from the walking beam and extends down inside the tubing far enough to keep the plunger inside the working barrel. The motion of the walking beam provides the reciprocating motion for the pump plunger. On the down stroke the lower valve closes and the upper valve opens to pass oil. On the up stroke the lower valve opens to admit oil and the upper valve closes to enable the plunger to lift the column of oil in the tubing.

The walking beam is actuated by a pitman connected to a crank on a gear-reduction unit. The latter is usually connected by a V-belt drive to the pumping motor. (A typical unit is shown on the COVER.)

The oil lifted through the tubing by the pump is discharged through the lead line shown in Fig. 1.

Pumping speeds vary widely, but generally range from 15 to 20 strokes per minute. A pumping speed under 10 strokes per minute is usually called slow-motion pumping. High speeds up to about 35 strokes per minute are used in some cases to obtain a profitable amount of oil when the well produces a high percentage of water.

Normal practice is to confine the work of the motor to pumping and to employ a portable hoist to pull the rods and tubing when it is necessary to make repairs or replace pump parts, or clean out the well.

Motors and Application Factors for Beam Pumping

The three-phase squirrel-cage induction motor is almost universally used for beam-well pumping. This motor is available in three types, which for brevity will

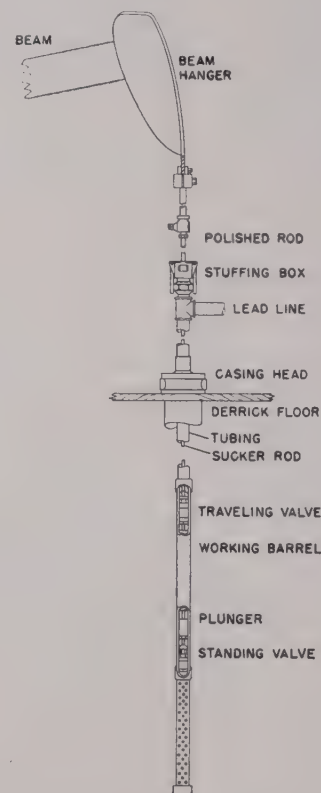


Fig. 1. Oil-well beam pump

be designated by letters. They are the normal-starting torque (NT) motor, the high-starting-torque (HT) motor, and the high-slip (HS) motor which also has high starting torque. For this service only motors rated on a continuous basis should be used.

TABLE I
OIL PRODUCTION METHODS

Producing Methods	Depth of Producing Well (feet)		Fluid Required to be Pumped from each Well (bbl per day)		Horsepower of Prime Mover Required per Well	
	Min	Max	Min	Max	Min	Max
(1). Beam Well Pumping.....	800	8,000	1	500	3	75
(2). Central-power Pumping.....	800	2,500	1	25	1	5
(3). Gas Lift.....	3,000	6,500	500	5,000	75	500
(3A). Intermittent Gas Lift.....	4,000	6,500	100	1,000	25	100
(4). Centrifugal Bottom-hole Pumping.....	1,500	6,500	1,000	3,000	25	200
(4A). Combination of No. 4 and No. 3.....	5,000	6,500	3,000	5,000	150	200
(5). Hydraulic Pumping.....	5,000	8,000	50	300	10	40
(6). Plunger Lift.....	3,000	6,500	100	1,000	25	100
(7). Pneumatic Rod Lift.....	3,000	6,500	50	500	25	100
(8). Casing Rod Pumping.....	1,000	2,500	2,000	3,000	25	50
(9). Swabbing.....	4,000	6,500	1,000	2,000	75	150
(10). Repressuring.....	800	7,500	5	25	10	100

Some or all of the following factors are involved in the selection of the most suitable type of motor.

(1). A rather high starting torque is required for a pumping unit. In cold weather the high viscosity of the grease or oil in the bearings and gear unit demands an especially high starting torque which may be out of proportion to the motor size. Therefore, small motors need a relatively higher starting torque in percentage of full-load torque than do large motors. The actual starting torque required, over a range of motor sizes used on pumping units, will not vary nearly as widely as the motor sizes.

It is customary to apply a motor with a high starting torque (approximately 250 percent of full-load torque), such as the HT or HS, when the rating is under 10 hp. For motors of 10 hp and larger, it is reasonably safe to apply the normal-starting-torque (NT) motor (approximately 150 percent of full-load torque), unless other reasons dictate the use of the HT or HS. On some specific applications it has been found advisable to use the HT or HS for 10-, 15-, or 20-hp sizes to insure sufficient starting torque. Such decisions must be based on local operating conditions. For example, HT or HS motors are often desirable for wells with paraffin troubles.

(2). On the normal duty cycle of a beam-pumping unit, there are two power peaks on each pumping stroke, one when the rods and oil are lifted, and the other when the counterweight is lifted. When the electric power supply is generated in a small isolated power plant, these recurring peaks of a group of wells will periodically coincide, as illustrated in **Fig. 2**, and result in unsatisfactory voltage regulation. Under these circumstances, and regardless of all other considerations, high-slip motors (having 8 to 13 percent slip instead of a normal of approximately three percent) should be used to reduce the current peaks (**Fig. 3**). If the power is purchased, or if the isolated power plant is large, either NT or HT motors can be used, provided other conditions are favorable.

(3). By slowing down as the peak load comes on, the high-slip motor allows energy stored in the rotating parts of the rig and motor to help carry the peak. Some operators desire this type of motor for the cushioning on the power system resulting from this speed variation. However, cushioning of mechanical shocks in this manner will be obtained only if the average strokes per minute are allowed to drop correspondingly, and even then the effect will be small.

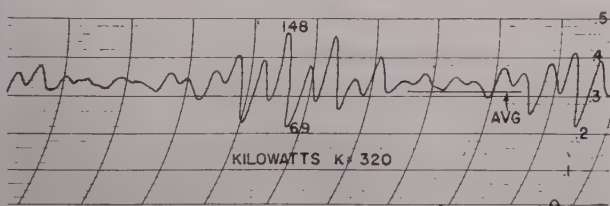


Fig. 2. Load characteristic of a group of beam-pumped wells

As this would probably decrease the production from the well and possibly give a speed out of resonance with the sucker rods, normal practice is to use different V-belt drive ratios for high-slip and normal-slip motors, so as to obtain the same pumping speed in either case. Under these circumstances there is no material difference in the mechanical shock loads and the only cushioning effect is that obtained in the electric input to the motor.

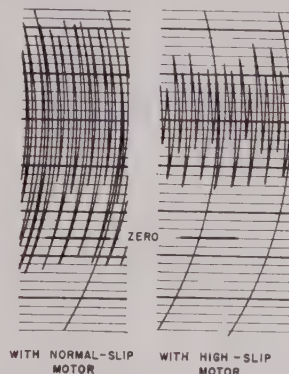


Fig. 3. Effect of a high-slip motor in reducing current peaks on a beam-pumped well

(4). High pumping speeds (30 to 35 strokes per minute), such as are used in many wells producing a very high percentage of water, result in high motor-input peaks even when the pumping units are properly counterbalanced. High-slip motors give the best results in such cases, as they reduce the current peaks and minimize the motor heating.

Although the efficiency of the high-slip motor is lower than that of the normal-slip motor, this does not necessarily mean that the former will have a higher power consumption. The reduction in current peaks effected by high slip reduces the power losses in proportion to the square of the current, which may more than offset the effect of the lower motor efficiency. Even this is not necessarily the result in all cases, as it depends on the conditions at each well. The net result may be an increase or decrease in power input, but too small to be a factor in the selection of the size of motor.

Guide to Motor Selection for Beam Pumping

In line with the foregoing considerations, the following guide to motor selection is offered to cover the most important factors. There are many other conditions in oil-well-pumping service which can influence motor selection, especially in borderline cases.

(A). The normal-slip, normal-starting-torque (NT) motor is usually applied when:

- (1). The motor size is 10 hp or more, and
 - (a). power is supplied from a large generating plant or from the power system of an electric utility
 - (b). the wells are properly counterbalanced and paraffin not excessive.

(2). The evidence obtained from tests, or from comparison with other wells, shows conclusively that 150 percent starting torque will be sufficient.

(B). The normal-slip, high-starting-torque (HT) motor is usually applied when:

- (1). The required motor is less than 10 hp, unless it is definitely known that an NT motor will be satisfactory.
- (2). Existing well conditions are not thoroughly known.
- (3). There is conclusive evidence that very high starting torque (up to 250 percent of full-load torque) is required.

(C). The high-slip, high-starting-torque (HS) motor is usually applied when:

- (1). Power is supplied from a small isolated generating plant. This recommendation holds true regardless of all other considerations.
- (2). The user desires the additional cushioning effect which the high-slip motor provides, as compared with a normal-slip motor.
- (3). Under any conditions, it is advisable to reduce the momentary current peaks.
- (4). An unusually high pumping speed is required, resulting in very high peaks—for example, when the water/oil ratio is high.

Both high-slip and medium-slip motors are available. As the slip permits the stored energy in the rig to carry part of the peak load, and as this stored energy is small under any circumstances, the high-slip motor should be used, so as to utilize the available stored energy as fully as possible.

Double- and Triple-rated Motors for Beam Wells

The triple-rated single-speed squirrel-cage induction motor has three horsepower ratings in the ratio of 10/7/4, obtained by changes in stator connections, and all at the same speed; the double-rated motor is the same with connections for the intermediate rating omitted. The main advantage of the lower ratings is to improve the power factor on the lighter loads. A slightly better efficiency may also be gained. Where the power

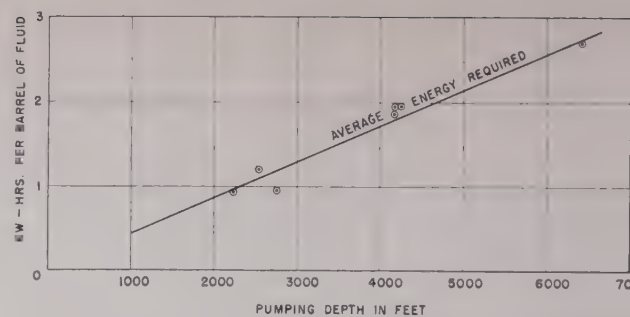


Fig. 4. Power consumption of beam-pumped wells listed in Table II

requirements of the various wells on a lease differ considerably, such a motor, applied in the same size to all the wells, will give maximum flexibility in the use of motors on light or heavy wells, while keeping the stock of spare motors and renewal parts down to a minimum.

In the initial stages of pumping after a well has ceased flowing, the lowest rating may be used, because the remaining reservoir pressure will still help to lift the oil. As this pressure declines, the intermediate rating and eventually the highest rating will be required. Then in time, as production declines, the lower rating may be used again. These changes of rating will also be advantageous to match changes in allowable production under proration rules. The highest rating may also be used for driving a friction-clutch rod and tubing hoist.

Recent trend has been away from this type of motor in favor of several sizes of single-rated motors, the practice being to change the motor size on a well to suit changing conditions. Generally a field does not require pumping to be started all at one time, but it begins on one edge and progresses across the field. The small sizes of motors are used at the front line, and large motors progressively to the rear.

Motor Enclosure for Beam Wells

Well-pumping motors are usually installed outdoors. They are available with dripproof, splashproof, totally enclosed fan-cooled, and explosion-proof frame constructions. The present trend is toward the use of dripproof motors where splashproof have been used extensively in the past. Under severe weather conditions the totally enclosed fan-cooled motor will give low

TABLE II
ELECTRIC POWER CONSUMPTION OF BEAM-PUMPED WELLS

Group	Number of Wells Pumped	Weighted Average Approx Depth of Wells (feet)	Barrels Actual Monthly Production				Actual Electric Energy Purchased (kw-hr)	Actual Kw-hr per bbl of Fluid	Percent Overall Efficiency Electric Motor to Fluid in Tank
			0.85 Oil	1.12 Water	Total Fluid				
					(bbl)	(sp gr)			
(a)	6	2,210	2,610	30,900	33,510	1.10	30,300	0.91	35.4
(b)	59	2,540	35,000	121,000	156,000	1.06	187,500	1.20	33.8
(c)	11	2,750	19,980	8,760	28,740	0.90	27,068	0.94	35.0
(d)	29	4,186	37,004	136,390	173,394	1.06	321,960	1.86	31.6
(e)	21	4,238	29,490	63,300	92,790	1.03	181,997	1.97	33.8
(f)	66	4,260	54,203	92,852	147,055	1.03	287,744	1.95	33.9
(g)	15	6,430	36,300	1,950*	38,250	0.86*	103,000	2.70	27.0

*Specific gravity of (salt) water = 1.15 for group (g).

service with less maintenance than either the dripproof or the splashproof motor. In a few places where heavy snow and sleet conditions prevail, dripproof motors enclosed in ventilated "doghouses" or sheds have been used. Explosion-proof motors are not normally required because the well is capped when the motor is operating, and the motor is shut down when the well is open.

Control for Beam-pumping Motors

Control equipment is assembled in a pole-mounted, ventilated, outdoor case. It normally includes a fused line switch, a motor-starting magnetic switch, a control switch, undervoltage and temperature overload protection, and, when required, an automatic time switch and a lightning protector.

Time-cycle pumping is used where production is prorated, or where stripper wells are pumped only a few hours a day. The time switch starts and stops the motor automatically at preadjusted times each day, and may be arranged to stop the pump one or more days a week if desired. Exact production schedules are thus met on time without attention from the pumper. Stripper-well production may be increased by proper timing. For example, in one case a well, pumped by manual control once a day, required 12 hr to fill to its maximum head, but filled to 70 percent of this head in six hours. By means of time-switch electric-motor control, it was pumped twice a day at 6-hr intervals, and

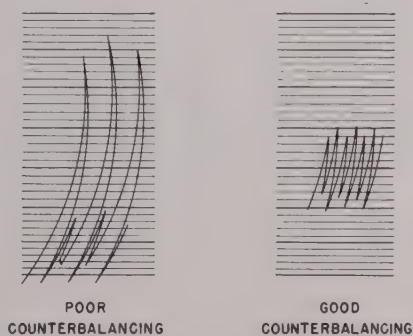


Fig. 5. Power input to two beam-pumped wells, illustrating the effect of counterbalancing

produced 140 percent (2×70 percent) of the oil previously produced—a gain of 40 percent.

Power Consumption for Beam Pumping

As oil wells differ in their characteristics, and the operating conditions of each change from time to time, estimates of electric power consumption are not only difficult to make but are likely to be inaccurate. When wells cease flowing and go on the pump, the power increases progressively as the reservoir pressure declines, and then eventually decreases as production declines. The point in the productive cycle at which electric drive is applied will govern, to a large extent, the power consumption to be anticipated.

Although the status of the production cycle was not available for the 207 wells listed in Table II, a consider-

able range of depth is covered, which makes it possible to plot the power-consumption curve shown in Fig. 4. This is a fairly representative curve, although for small producers increasingly higher average kw-hr per bbl can be expected with increase in depth.

Effect of Counterbalancing Beam Wells

A walking-beam pumping unit is counterbalanced by weights mounted on the end of the beam or on the crank. By adjustment they offset the weight of the

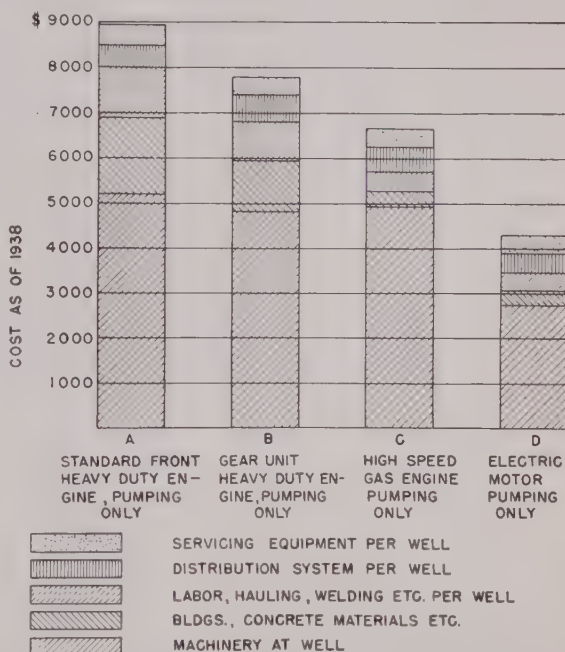


Fig. 6. Comparative installation costs of four types of beam-pumping equipment in Mid Continent oil fields

rods in the well plus about half of the weight of the oil lifted on each stroke.

The best possible counterbalancing makes the two power peaks equal (Fig. 5). This can be checked readily by a portable ammeter.

Proper counterbalancing not only reduces the torque required to rotate the crank but also minimizes the power consumption because of the reduction in losses.

Beam-well Cost Considerations

Because of the wide variation in operating costs as well as conditions, it is practically impossible to prepare a general cost comparison between electric drive and other forms of power which will be of much value for consideration of specific applications. Consideration of costs will therefore be confined essentially to a few comments.

A chart of relative installation costs of four types of beam-pumping equipment is shown in Fig. 6. As the costs were determined in 1938, they will be far from correct now, but the comparison is of interest. The data were derived from reliable contractors and equipment manufacturers, and apply to Mid Continent wells producing 300 to 400 bbl per day from a depth of approximately 4000 ft and equipped with 40-hp engines or

25-hp motors. Another comparison, shown in **Fig. 7**, is based on costs (1940-1941) in Illinois oil fields, covering electric motors and multi-cylinder gas engines.

In figuring operating expenses, some operators are inclined not to give due consideration to fixed charges, which are of course important factors. Before the war,

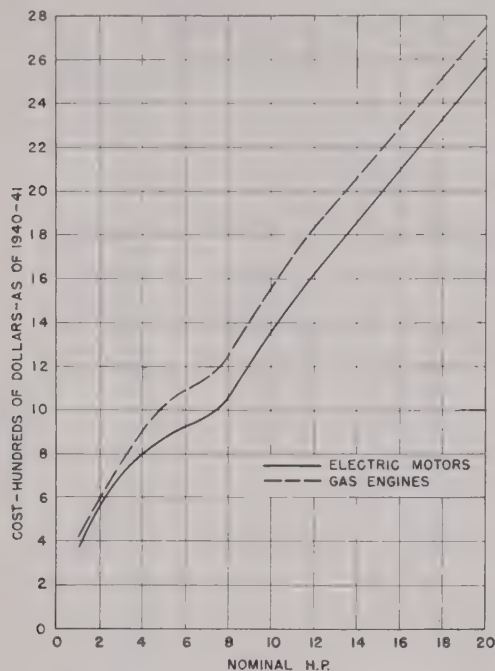


Fig. 7. Comparative installation costs of beam-pumping units in Illinois

interest was usually figured at six or seven percent, but varied with the locality and the apparent risk involved. Depreciation of ten percent per year is conservative. Taxes and insurance average about three percent per year.

Operating costs include power, labor, and maintenance. Gas used should be charged at its marketable value, if any. Labor cost will depend on the number of wells which can be attended by each pumper. Maintenance includes costs of repairs, renewal parts, reconditioning, and lubrication. In making comparisons between various forms of power, consideration should also be given to loss of production due to shut-downs and to the relative amount of rod breakage experienced. Shut-downs may not be important on part-time producers, but rod breakage can be so on any beam well. For example, on a West Virginia property, installation of electric drive resulted in the practical elimination of rod breakage on wells where breakages had previously averaged one a year per well. Under similar circumstances in Venezuela, rod failures which had averaged between 3 and 4 a year per well were reduced over 80 percent after electrification.

Central-power Pumping

In central-power pumping, the power from a single motor is transmitted mechanically to a group of wells through a pull-rod system. The motor drives a vertical-shaft eccentric, and pull rods are hooked to the eccen-

tric strap. They extend horizontally to the several wells, where they actuate pumping jacks, similar to bell cranks. To these are attached the sucker rods in the wells. The motor drives the rig through either a bevel-gear drive (**Fig. 8**) or a large vertical-shaft bandwheel with belt drive. The direction of pull of each well on the eccentric is so laid out, by mechanical means, that the wells counterbalance each other. When the wells are pumped intermittently, they are hooked to the "power" on a staggered schedule and the "power" runs continuously.

Experience furnishes the only practical rule for estimating the power requirements. Records of a large number of very shallow wells (1000 ft or less) show an average of 1.5 hp per well, and a minimum of less than 1 hp. Power consumption of several groups of wells is shown in Table III.

A standard squirrel-cage or wound-rotor induction motor with simple starting and protective equipment usually meets all requirements for central-power pumping.

Gas Lift

The gas-lift method of oil production is occasionally used. It employs compressed natural gas to blow the

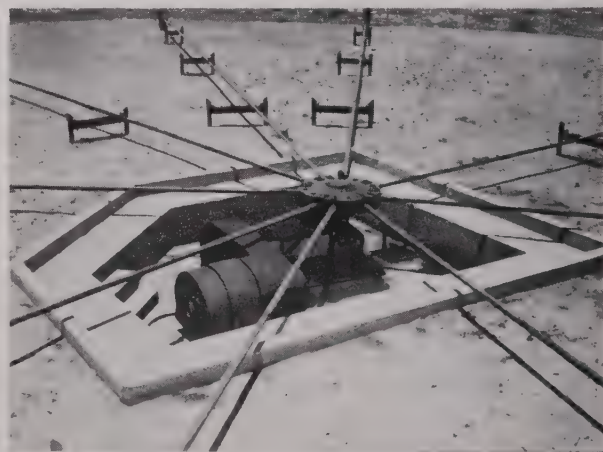


Fig. 8. Motor-driven geared pumping "power"

oil out of the well. Air may be used sometimes when there is insufficient gas. By the simple method illustrated in **Fig. 9**, the gas is forced down through a pipe suspended in the hole, and blows the oil up through the tubing.

A group of 75- or 100-hp compressors, according to the oil company's individual requirements, is the usual type of installation. Standard squirrel-cage induction motors are used to drive the compressors.

Because all of the heat of compression of the gas is lost, this is a costly method of producing oil, but it has the advantage of being able to handle large volumes of fluid.

Centrifugal Bottom-hole Pumping

A well with heavy potential production in excess of the capacity of deep-well reciprocating pumps can be

pumped with a submersible centrifugal pumping unit. Such a unit consists of a cylindrical multistage centrifugal pump driven by a high-speed squirrel-cage induction motor of the same diameter, and directly coupled to the pump with an intervening sealing unit. The complete unit is suspended in the well by tubing, and receives electric power through a cable clipped to the tubing. The required motor capacity depends on the number of stages in the pump. Sizes available range from 52.5 hp in 4½-in. outside diameter and 97.5 hp in

Hydraulic Pumping

This method employs a double-acting deep-well reciprocating pump actuated by a direct-connected power piston which is operated by oil under pressure. The pump is suspended in the well on tubing and submersed sufficiently to insure filling of the pump cylinder on each stroke. The oil to actuate the power piston is supplied by a triplex pump located above ground and driven by a squirrel-cage induction motor. This oil is pumped down to the power cylinder through a small

TABLE III
ELECTRIC POWER CONSUMPTION OF WELLS PUMPED BY CENTRAL POWERS

Group	Number of Wells Pumped	Average Length of Pull Rods (feet)	Weighted Average Approx Depth of Wells (feet)	Barrels Actual Monthly Production				Actual Electric Energy Purchased (kw-hr)	Actual kw-hr per bbl of Fluid	Percent over-all Efficiency Electric Meter to Fluid in Tank
				0.85 Oil	1.12 Water	Total Fluid				
						(bbl)	(sp gr)			
(a)	5	1,320	2,600	6,480	5,000	11,480	0.97	12,170	1.06	31.6
(b)	13	1,100	2,600	7,320	11,800	19,120	1.02	18,900	0.99	35.6
(c)	9	780	2,600	9,800	3,590	13,390	0.92	10,770	0.81	39.6
(d)	8	1,400	2,600	5,550	12,600	18,150	1.04	14,300	0.79	45.2
(e)	14	1,100	2,600	4,720	24,020	28,740	1.07	19,700	0.69	53.0
(f)	11	800	2,600	5,000	9,000	14,000	1.02	14,400	1.03	34.1
(g)	8	750	2,750	1,410	3,870	5,280	1.04	7,500	1.42	26.7
(h)	4	460	2,770	1,140	3,660	4,800	1.06	8,040	1.67	23.2
(i)	12	1,180	2,380	12,000	1,680	13,680	0.89	11,000	0.80	34.9
(j)	12	1,235	1,250	10,500	100	10,600	0.85	3,500	0.37	38.0

5¾-in. outside diameter up to 135 hp in 5⅞-in. outside diameter, providing for all well depths down to 10,000 ft. Power consumption is approximately ⅓ kw-hr per barrel of fluid produced per 1000 ft of lift. The efficiency of the pumping unit is approximately 30 to 45 percent.

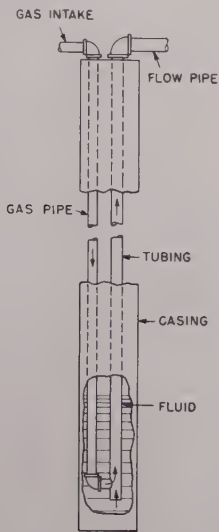


Fig. 9. A simple form of gas lift

Supplementary equipment includes a cable reel, a starting panel, and either a special transformer or a special a-c generator. About 900 volts must be available above ground to allow for the voltage drop in the cable leading to the motor.

string of tubing suspended inside the larger tubing, and is then discharged into the stream of oil produced from the well, which is pushed to the surface in the annular space between the two strings of tubing.

Equipment is available for pumping wells from 1500 down to 10,000 ft on either single- or multiple-well hookups.

Power consumption is approximately 1.4 kw-hr per barrel of fluid for a pumping depth of approximately 6400 ft, or 0.22 kw-hr per barrel per 1000 ft of lift. The horsepower required depends on the pump size.

Secondary Recovery by Water-flooding

Water-flooding operations involve the injection of water at high pressure into the oil-bearing formation to force the oil to key wells, which are usually pumped by beam-pumping units or central "powers." The water supply is usually pumped from deep wells or lifted by compressed air. It is then chemically treated and filtered, pumped through a pipe line to the oil field, and forced underground by high-pressure injection pumps. The application of electric drives to these operations follows standard practice for the types of apparatus involved.

Control equipment for water-flooding systems must be completely reliable. Shutdowns must be avoided if possible, because they mean loss of production and possible detrimental effect on the progress of water flooding. Simple, automatic operation shortens many unavoidable shutdown periods, lowers the labor cost

per barrel, saves time and reduces maintenance costs. The judicious employment of automatic motor starters, electric float switches, pressure switches, and time switches will accomplish these purposes readily.

A few points deserve special mention. If an electric power failure stops a deep-well centrifugal water pump, the water standing in the vertical discharge pipe will rotate the pump backwards unless there is a ratchet head or other nonreversing device. If power is restored during reverse rotation, the pump shaft may be twisted off, but this can be obviated by a time relay which will keep the motor from starting until the pump has had time to stop running backward.

Injection pumps must be protected against loss of suction pressure. A pressure switch, operating on pump-suction pressure, is adjusted to trip the motor starter when the pressure goes below the permissible minimum. This also prevents the pipe line from filling with air.

Excessive voltage drop resulting from simultaneous automatic restarting of a large number of motors can be avoided by restarting in successive groups controlled by definite-time-delay relays. This also avoids the danger of collapsing the suction manifold of a group of pumps before the water has time to get to the pumps.

Repressuring

To maintain the underground reservoir pressure and thus prolong or increase well flow, natural gas stripped of condensates is returned under pressure to the oil-producing formation in many fields. Steam is usually required in processing the gas, and can be first used to generate electric power. Before a specific plant is designed, a careful economic comparison should be made between the steam-electric and the gas-engine system, because the market value of excess gas is increasing, steam-electric maintenance costs are comparatively low, and the demand for electrified auxiliaries is increasing.

A typical steam-electric plant uses steam turbine-generators, motor drives for compressors and pumps, cooling-tower motors and control, auxiliary motors, switchgear, unit substations, auxiliary power transformers, and lighting equipment.

ELECTRIC POWER DISTRIBUTION FOR WELL PUMPING

Approximately two thirds of the cost of electrification of an oil field is for the power-distribution system; the remaining one third is for the motors and control. It is therefore quite important that the distribution system be laid out carefully, with due consideration of cost.

The factors which affect the layout and type of the distribution system are: permissible voltage drop; cost of system; number and sizes of motors; well spacing; configuration of the field; pole spacing; size and type of line wire; power factor; and service reliability.

A system usually consists of 2400-, 4160-, or 13,800-volt primary feeders extending into the field, with transformers at strategic locations stepping down to 480 volts for supplying a group of wells. The load is

much more widely distributed than in ordinary industrial plants, and each well is usually relatively small in horsepower requirements. The load distribution makes it necessary to run secondary feeders for as great a distance as voltage conditions will permit.

Voltage Drop

Voltage drop is the main consideration in the layout. Motor current is commonly supplied at 440 volts over long feeders, with a low operating power factor; and voltage drop to a large extent determines the cost of the system. Good practice requires that the operating voltage, after the motors are started, should not be less than 95 percent, nor more than 110 percent, of the motor nameplate voltage. Although motors will operate at less than 95 percent, and manufacturers guarantee noninjurious temperatures with operation at 90 percent of motor nameplate voltage, a minimum operating voltage of 95 percent allows some margin for the voltage drop occasioned by starting a motor. These limits of 95 and 110 percent are permissible in oil field practice, though they have a slightly wider spread than generally recommended by the AIEE Subcommittee on Industrial Voltage Requirements.⁽¹⁾

The voltage at the motor during starting should be at least 80 percent and preferably 85 percent of the motor nameplate voltage. Flicker of field lights at the time a motor is started is not important.

In a well-planned system the voltage drops will ordinarily be from one to three percent in the primary line, two to four percent in the transformers, and 7½ to 12½ percent in the secondary line. The total drop at the most remote well should not be more than 15 percent of the no-load voltage, which will give approximately 95 percent of motor nameplate voltage at the motor terminals when using a transformer tap to give 5 percent above rated transformer voltage. If capacitors are used, the drop becomes approximately 10 to 12½ percent instead of 15 percent. Obviously, secondary lines should be as short as possible. For this reason it is preferable to use the load-center principle of power distribution, in which power at primary voltage is brought directly to the load area before it is stepped down to distribution voltage.

If utility power is used, the primary voltage will be fixed by the utility practice, but if it can be selected, 4160 volts results in very much less drop than 2400 volts, at almost the same cost, and allows for future expansion. Higher primary voltages are seldom necessary and are not as economical.

Compensation for voltage drop may be made by the use of transformer taps, or by capacitors, or both.

Distribution Transformer Banks and System Protection

Single-phase transformer units are preferable. Generally transformer banks up to 45 kva and sometimes up to 75 kva are pole-mounted on cross arms. Above these sizes a double-pole and platform arrangement is commonly used. The transformers are of standard design,

⁽¹⁾See correspondingly numbered references at end of article.—Ed.

readily obtainable, easily handled, require a minimum of spare parts, and can still supply power at reduced capacity in the event of outage of one transformer of a delta-delta-connected bank. The delta-delta connection is preferable, not only for this reason, but also because standard two-coil overload protection of motors can be used. A wye-delta or delta-wye connection requires three-coil overload protection for each motor to avoid

they release substation and line capacity for additional load (Fig. 10), or permit the use of smaller transformers and conductors, and will reduce the cost of utility power if the rate contract includes a power-factor penalty clause.

Capacitors can be connected either at the motor terminals or on the feeder lines. The advantages and disadvantages of both methods of connection should be

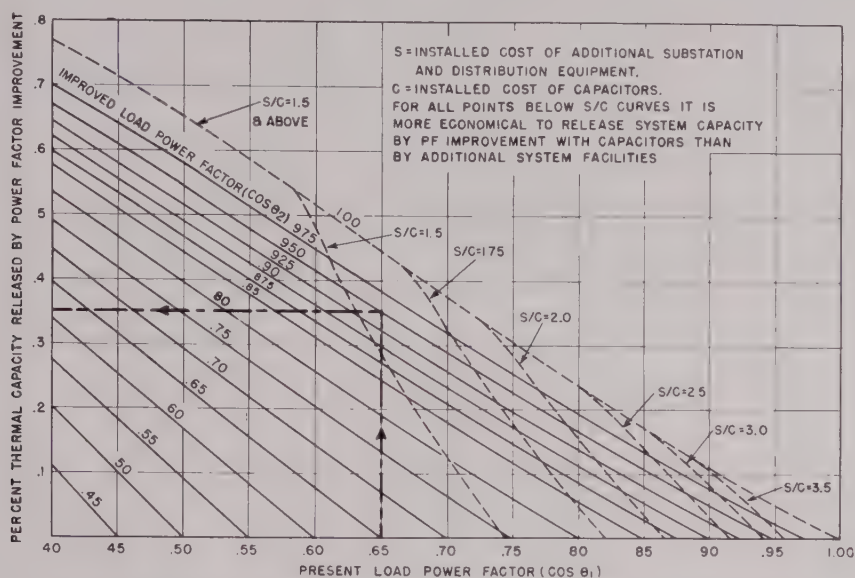


Fig. 10. System thermal capacity released by improving load power factor. For example, if the power factor of a circuit is improved from 65 to 95 percent, the system can carry 35 percent additional 65-percent-power-factor load without exceeding the original kva, and capacitors are more economical than additional system facilities for all S/C values above 1.55

burnouts in case a primary fuse or line is open and the bank has an ungrounded neutral. In such a case double current will occur in one secondary conductor, and two-coil overload relays will not then provide full protection.

Lightning arresters should be included at each substation for maximum protection. The 440-volt systems are invariably ungrounded, so secondary arresters should be selected for ungrounded service. Fused cut-outs are economical and are almost universally employed to protect transformer-bank sizes normally used in oil-field distribution service.

If oil company practice permits the bonding of electrical connections to the well casing, this will provide a suitable ground for the pumping-unit frame, motor-starter case, and lightning arresters. The usual alternative is to use ground rods.

Capacitors

In a 440-volt system, it is expensive to reduce the voltage drop by increasing the conductor size. Capacitors are the answer to that problem, by improving the normally low power factor of well-pumping loads, which is approximately 60 to 65 percent. The saving in system losses by the use of capacitors is often economically attractive, as the losses are inversely proportional to the square of the power factor. In oil-field distribution systems, with relatively long secondary runs, it is not at all unusual for capacitors to pay for themselves through reduction in system losses alone. Furthermore,

weighed to determine the choice, which depends mainly on the ratio of the number of wells in operation to the total number of wells pumped. If all are pumped simultaneously, capacitors at individual motors are preferable, but it is uneconomical to use the outdoor type for motors under 10 hp. If only part of the motors are in operation at any time, the group-capacitor method should be considered because of the lower investment.

Type of Line Conductor

In "sour" gas areas, steel-reinforced aluminum conductors are generally used instead of copper because aluminum is noncorroding. The spans between poles for 440-volt line construction can be from 300 to 500 ft with aluminum, compared with 150 to 350 ft with copper. Thus, the pole cost for aluminum lines is roughly half that for copper lines. Since pole cost is an appreciable part of the total cost, aluminum conductors represent a large saving. For equivalent conductor size, the voltage-drop and wire costs are about equal. Greater care is required in making satisfactory splices and terminations with aluminum.

System Layouts

The layout of an oil-field distribution system is based upon considerations of voltage drop, power factor, and motor-starting conditions, with due regard to the

(Concluded on next page)



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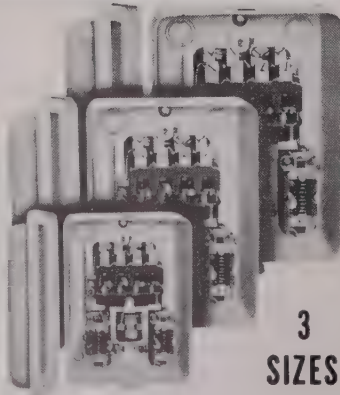
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requirements at remote well locations. Information for making a layout of an oil-field distribution system has been published⁽²⁾ in the form of load charts, tabulations and plots of voltage drop for primary and secondary conditions. This previously published material includes also the data for estimating the installed cost of distribution systems. These data permit quick cost comparisons of various alternative layouts which are useful in arriving at the most economical layout for a given field.

Acknowledgments

For considerable data used, the writer is indebted to many engineers, particularly to W. H. Stueve of the Oklahoma Gas & Electric Company and L. S. Peterman of the Southern California Edison Co.; also to W. C. Bloomquist and J. N. Poore of the General Electric Company.

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(1) "Report on Industrial Voltage Requirements," by AIEE Committee on Industrial Power Applications (Subcommittee on Industrial Voltage Requirements), *AIEE Miscellaneous Paper 47-157*, presented at AIEE summer general meeting at Montreal, Quebec, Canada, June 9-13, 1947.
(2) "Power Distribution Systems for Oil-field Pumping," by W. C. Bloomquist and J. N. Poore. *The Oil Weekly*, Dec. 23, 1946, p. 46; Dec. 30, 1946, p. 54; and Jan. 13, 1947, p. 46; also General Electric publication GET-1425.

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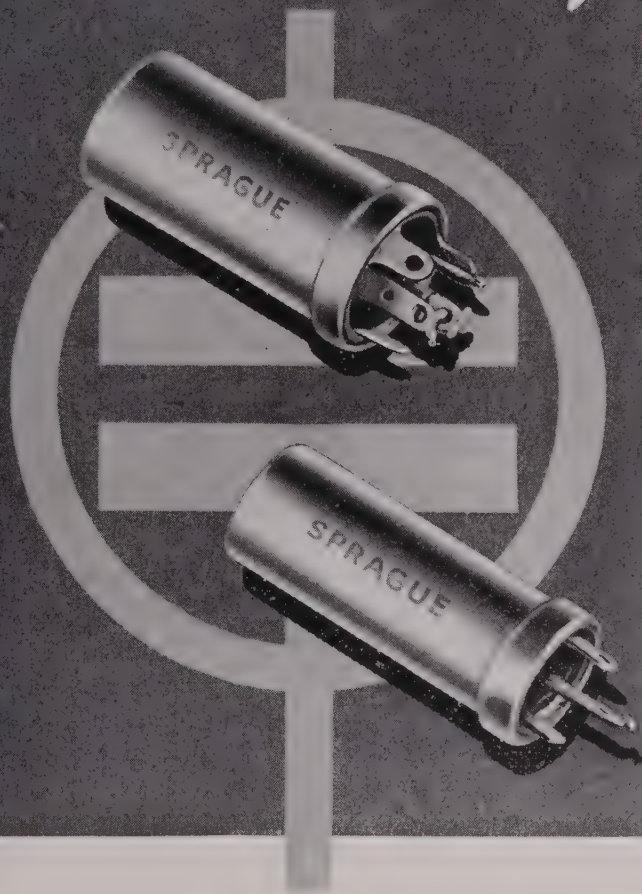
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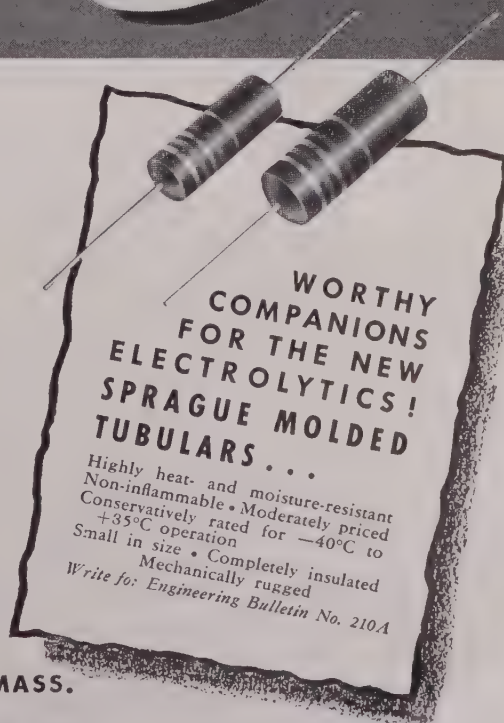


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UNBALANCED RESISTANCE AND SPEED-TORQUE CURVES

A correlation of some of the effects of unbalanced secondary resistance upon the speed-torque characteristics of three-phase induction motors

By B. W. JONES

Control Engineering Division, Apparatus Department
General Electric Company



B. W. Jones

THREE-PHASE induction motors of the wound-rotor type are useful for accelerating heavy loads and also where speed must be controlled over a wide range. This speed control is generally accomplished by manipulation of resistance in the rotor circuit. In the inserting or removal of the required amounts, the preferred method is to always have the same total amount of resistance in each of the three legs of the rotor (commonly referred to as a balanced resistance); but when a manually controlled

the control. A comprehensive investigation of the effects of various combinations of resistance in the leg of a three-phase rotor circuit requires long, tedious test. The result of such a test, in the form of speed torque characteristics, however, provides an instructive index to wound-rotor performance.

The analysis of a series of tests performed upon a 22-hp six-pole 1200-rpm three-phase 220-volt wound rotor induction motor will serve to exemplify the nature and trends of performance of motors with various amounts of unbalanced rotor resistance. The plotting of test points as per cent values gives wide quantitative usefulness to the curves. Reproductions of a series of these curves thus are a useful supplement to available literature as a guide in the selection of the resistor elements of motor control.

Three general combinations of resistors were used in this test. One combination consisted of a resistor in only one leg of the rotor circuit, as shown in Fig. 1. The second combination contained resistors in two of the three legs as shown in Fig. 2; the third combination contained resistors in all three legs. The degree of unbalancing is shown in Table I, which gives percentage values for the several combinations of resistor ohms that were used. In this percentage representation, 100 per cent resistance represents that value of ohms which if put in each of the three rotor legs, will allow rated torque to be produced when rated voltage is applied to

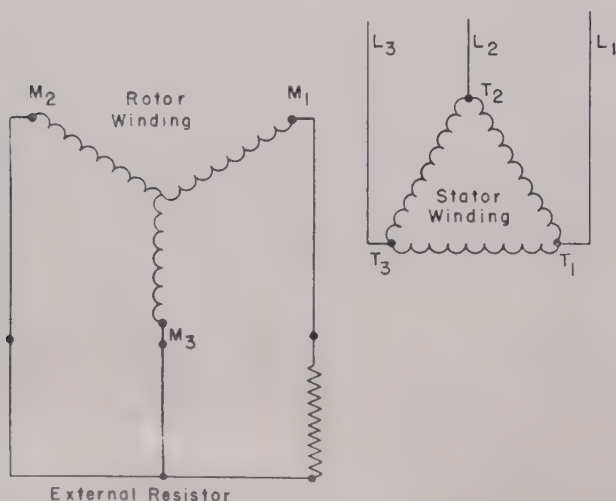


Fig. 1. Schematic connection diagram showing the location of an external resistor in one leg of a three-phase induction-motor circuit

drum or cam controller is used for short-circuiting this resistance, the resistance is very commonly short-circuited in an unbalanced manner. This unbalanced condition results from the fact that the controller removes the resistance in only one leg for each point of the controller. To do otherwise would generally result in an excessive size of controller that would be difficult for the operator to manipulate.

A Guide to Wound-rotor-motor Performance

It is surprising to find that very little information is available concerning the speed-torque characteristics of wound-rotor type of induction motors and the effects of various degrees of unbalanced resistances used with

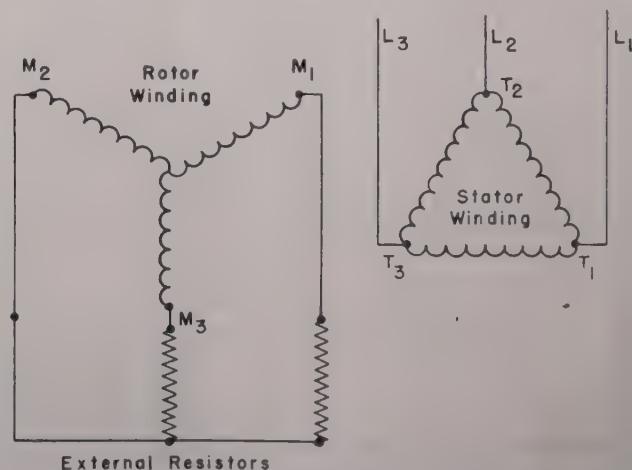


Fig. 2. External resistors in two legs of the rotor circuit of a three-phase induction motor

This article is so paged that, without mutilating other articles, it can be readily removed for filing as a group of full-size consecutive pages.—Ed.

Figs. 3 and 4. Speed-torque characteristics of a 22-hp 1200-rpm 220-volt three-phase wound-rotor induction motor with balanced and unbalanced conditions in rotor circuit (external resistance in only one leg)

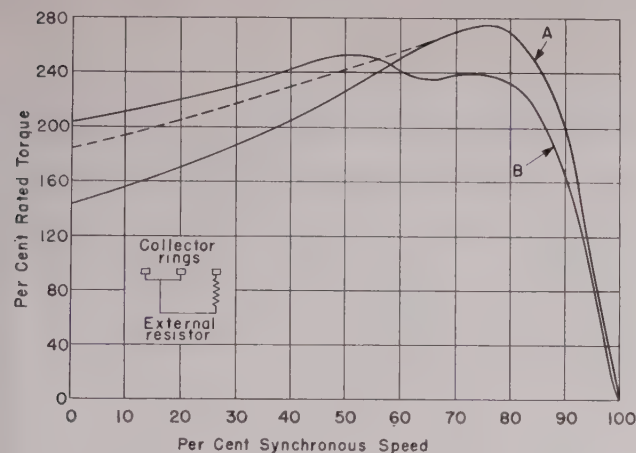


Fig. 3. Curve A: Theoretical curve for total resistance of 5 per cent when balanced

Curve B:	Motor	External	Total Resistance
	3.8	+	0
			= 3.8% in leg 1
	3.8	+	0
			= 3.8% in leg 2
	3.8	+	5.06
			= 8.86% in leg 3
			Average = 5.49%

The dotted portion of Curve A indicates approximately the effect of rotor heating

the stator phases. The rotor used in the tests upon which this article is based had 3.8 per cent ohms in each leg of its wye-connected winding, which means that only 96.2 per cent resistance was needed in the external section to provide 100 per cent total.

General Considerations

The speed-torque characteristics with balanced resistances in the rotor circuit are quite well known for wound-rotor motors in general; and, for purposes of comparison with unbalanced conditions, in this article a maximum torque of 275 per cent of rated torque is assumed. On each of the speed-torque characteristic curve plots there will be shown both the test speed-torque characteristic curve resulting from the unbalanced resistance in the rotor circuit and also the theoretical speed-torque characteristic curve resulting

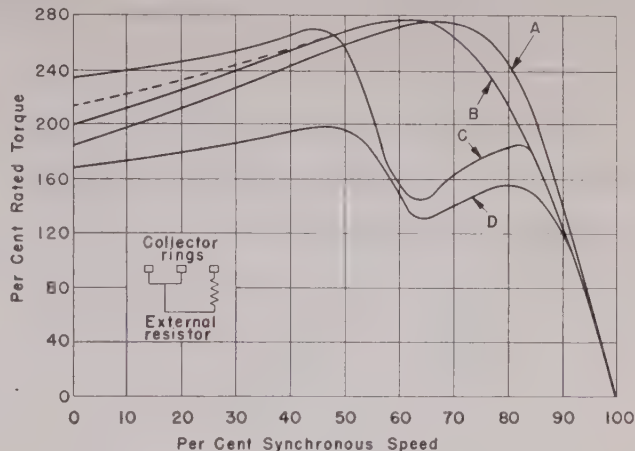


Fig. 4. Curve A: Theoretical curve for total resistance of 7 per cent when balanced

Curve B: Theoretical curve for total resistance of 9 per cent when balanced

Curve C:	Motor	External	Total Resistance
	3.8	+	0
			= 3.8% in leg 1
	3.8	+	0
			= 3.8% in leg 2
	3.8	+	14.87
			= 18.67% in leg 3
			Average = 8.76%
Curve D:	Motor	External	Total Resistance
	3.8	+	0
			= 3.8% in leg 1
	3.8	+	0
			= 3.8% in leg 2
	3.8	+	9.95
			= 13.75% in leg 3
			Average = 7.12%

from a balanced resistance in the rotor circuit of the same ohmic value as the average unbalanced value. The tests were made at 120 volts, instead of at the rated 220 volts, because of the rapid rise of the temperature in the motor windings. By increasing the resultant test torques by a factor of $\frac{220^2}{120^2} = 3.4$ approx.

the torque value that would result from test at 220 volts is obtained. Cases will be shown later where this factor of 3.4 does not hold; but in general it gives values which check very closely with rated-volt torque.

Unbalanced Resistance in One Leg

Figs. 3 and 4 show the tested speed-torque characteristic curves where the secondary resistances are in

TABLE I
EXTERNAL RESISTOR COMBINATIONS AND STATOR VOLTAGES USED FOR TEST

Resistor Combination	Test Volts on Stator	Per Cent Internal Resistance of Rotor per Leg	Per Cent External Resistance			Per Cent Average of Total Resistances	Speed-torque Plot
			Rotor Leg 1	Rotor Leg 2	Rotor Leg 3		
Resistor in one leg only	120	3.8	0	0	5.06	5.49	Curve B, Fig. 3
	120	3.8	0	0	9.95	7.12	Curve D, Fig. 4
	120	3.8	0	0	14.87	8.76	Curve C, Fig. 4
Resistors in two legs	120	3.8	0	5.06	5.18	7.21	Curve B, Fig. 5
	120	3.8	0	7.82	12.25	10.49	Curve B, Fig. 6
	120	3.8	0	12.25	17.18	13.61	} Curve B, Fig. 7
	120	3.8	0	14.65	14.82	13.62	
Resistors in three legs	120	3.8	5.06	5.18	10.25	10.76	Curve B, Fig. 8
	120	3.8	5.06	10.25	17.18	14.63	Curve B, Fig. 9
	120	3.8	12.25	17.18	26.95	22.59	Curve B, Fig. 10
	120	3.8	14.65	14.95	99.99	47.00	Curve B, Fig. 11
	120	3.8	17.18	62.00	102.20	64.26	Curve B, Fig. 12
Resistors in three legs	220	3.8	5.06	10.25	17.18	14.63	Points X, Curve B, Fig. 9
	220	3.8	14.65	14.95	99.99	47.00	Broken line, Fig. 11

Figs. 5, 6, and 7. Speed-torque characteristics of the motor with balanced and unbalanced conditions (external resistance in two legs)

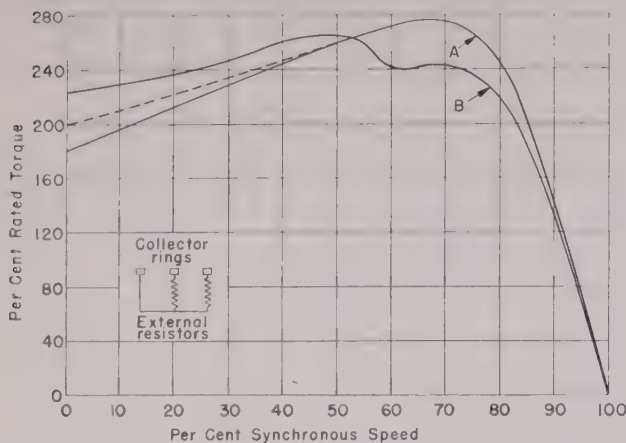


Fig. 5. Curve A: Counterpart of Curve A, Fig. 4 (7 per cent total resistance)

Curve B:	Motor	External	Total Resistance
	3.8	+	0
	3.8	+	5.06
	3.8	+	5.18
			Average = 7.21%

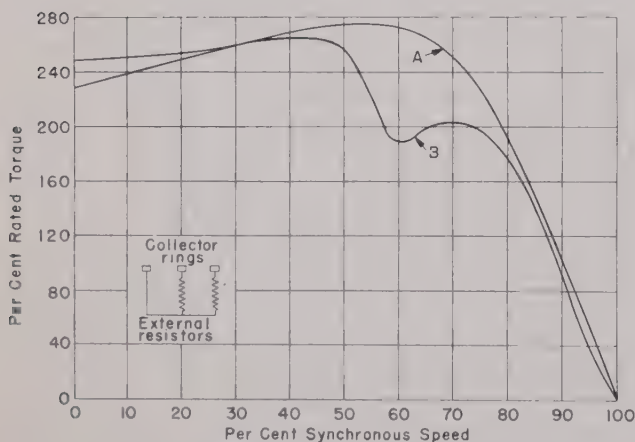


Fig. 6. Curve A: Theoretical curve for total resistance of 10 per cent when balanced

Curve B:	Motor	External	Total Resistance
	3.8	+	0
	3.8	+	7.82
	3.8	+	12.25
			Average = 10.49%

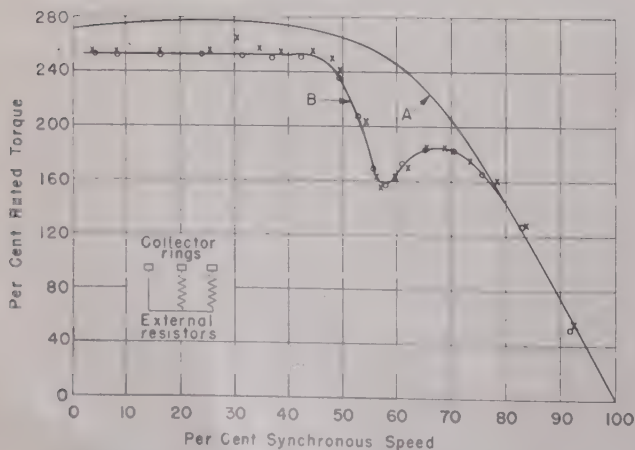


Fig. 7. Curve A: Theoretical curve for total resistance of 14 per cent when balanced

Curve B:	Motor	External	Total Resistance
Points ×	3.8	+	0
	3.8	+	12.25
	3.8	+	17.18
			Average = 13.61%
Points ○	3.8	+	0
	3.8	+	14.82
	3.8	+	14.65
			Average = 13.62%

accordance with the first group of combinations in Table I together with the nearest average balanced resistance speed-torque curves.

In Fig. 3 the unbalanced torque is less than the balanced torque between 60 and 100 per cent speeds, but the curves cross, and the reverse is true below 60 per cent speed. However, it should be kept in mind that for the balanced-resistance torque curve the total resistance in the rotor circuit is assumed to remain at five per cent, whereas actually in the tested condition the internal rotor resistance which is recorded as 3.8 per cent when cold must have reached perhaps five per cent or more during the period when the torques were being read. Therefore, it would be reasonable to assume that, had this motor's balanced speed-torque characteristic been obtained in the same manner as the unbalanced characteristic, the section of the balanced curve to the left of 70 per cent speed would be lifted so that the left end would have terminated at a point nearer 200 per cent torque. This is shown in Fig. 4 where the total resistance is assumed to be increased. Therefore, a dotted curve is drawn which will approximate the effect of the increased balanced torque due to the heating of the rotor. This same dotted curve will be shown on some of the other speed-torque characteristics in this article.

In Fig. 4 it should be noted that the torque for the higher unbalanced resistance (Curve C) is appreciably above that for the next lower value (Curve D). The direction but not the magnitude is such as would be expected on the low speed range; but it is opposite to that expected between the 50 to 90 per cent speed range. It should be kept in mind, however, that the magnitude of the torque dip around the 60 per cent speed range is greater than would have been experienced had the test been carried out at rated 220 volts. (The discrepancy is explained on the basis of iron saturation.)

Unbalanced Resistance in Two and Three Legs

Figs. 5, 6, and 7 show the speed-torque curve for the resistor combinations in which unbalance occurs in two legs of the rotor circuit. The variation from the corresponding balanced curves is not very pronounced, as would be expected, because the degree of unbalancing is less. Figs. 8 to 12 inclusive are the speed-torque curves for the resistor combinations summarized in the third grouping in Table I. These curves still further approach the corresponding balanced-resistance torque curve. In Figs. 8 and 9 are shown, as dashed lines, two of the combinations from the second group in Table I just to show graphically how two-legged resistor unbalance compares to three-legged resistor unbalance where the over-all averages are approximately the same. It will be noted that there is a more pronounced dip (at approx. 60 per cent speed) with the two-legged resistors. It should be especially noted, in Fig. 9, that the three-legged combination was tested at both 120 and 220 volts and that the curve calculated from the 120-volt data (using the 3.4 multiplier) checks ver-

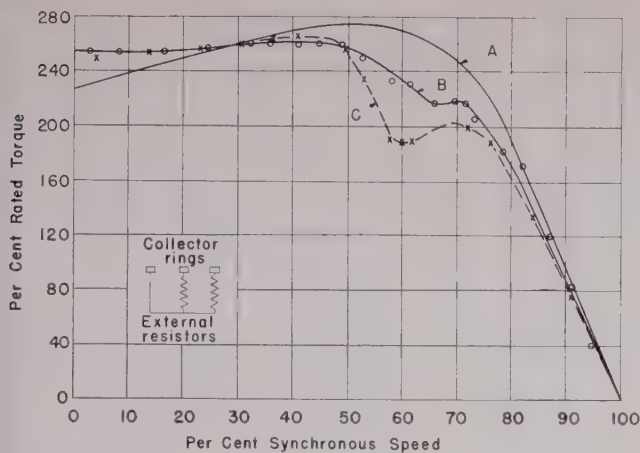


Fig. 8. Curve A: Counterpart of Curve A, Fig. 6 (10 per cent total resistance)

Curve B:	Motor	External	Total Resistance
Points ○	3.8	+ 5.06	= 8.86% in leg 1
	3.8	+ 5.18	= 8.98% in leg 2
	3.8	+ 10.25	= 14.05% in leg 3
		Average	= 10.76%
Curve C:	3.8	+ 0	= 3.8% in leg 1
Points X	3.8	+ 7.82	= 11.62% in leg 2
(Broken line)	3.8	+ 12.25	= 16.05% in leg 3
		Average	= 10.49%

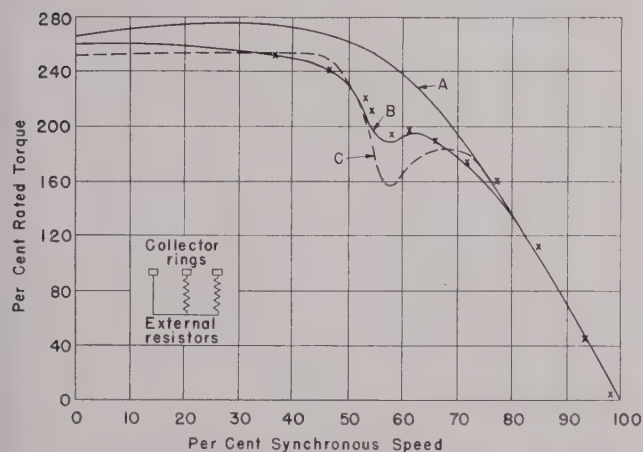


Fig. 9. Curve A: Theoretical curve for total resistance of 15 per cent when balanced

Curve B:	Motor	External	Total Resistance
	3.8	+ 5.06	= 8.86% in leg 1
	3.8	+ 10.25	= 14.05% in leg 2
	3.8	+ 17.18	= 20.98% in leg 3
		Average	= 14.63%

This curve was plotted from tests made at 120 volts, from which the torque was calculated for 220 volts. The points X are test values at 220 volts

Curve C:	Motor	External	Total Resistance
	3.8	+ 0	= 3.8% in leg 1
	3.8	+ 14.65	= 18.45% in leg 2
	3.8	+ 14.82	= 18.62% in leg 3
		Average	= 13.62%

This curve is the counterpart of Curve B, Fig. 7.

closely with the test results at 220 volts even around the 60 per cent speed range. It is only when the unbalance becomes quite pronounced that the partial voltage test results produces a result that does not check with the test at rated volts. This is shown in Fig. 11.

Fig. 11 graphically shows the resultant large difference in torque dips at approximately half speed when tested at 120 and at 220 volts. This shows up as a maximum when one of the rotor phases is completely open-circuited (that is, having infinite resistance in one phase). The last resistor combination listed in Table I

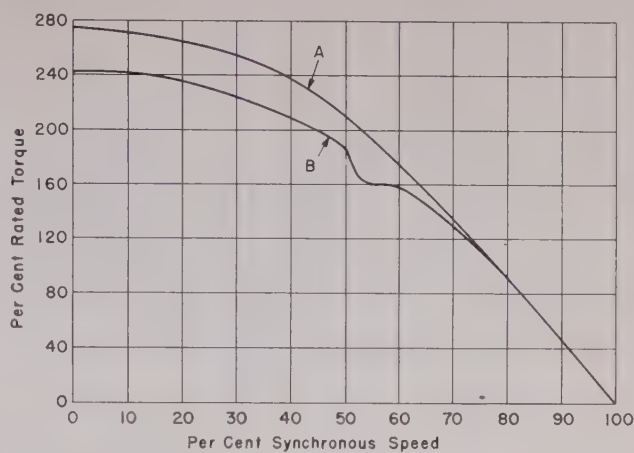


Fig. 10. Curve A: Theoretical curve for total resistance of 23 per cent when balanced

Curve B:	Motor	External	Total Resistance
	3.8	+ 12.25	= 16.05% in leg 1
	3.8	+ 17.18	= 20.98% in leg 2
	3.8	+ 26.95	= 30.75% in leg 3
		Average	= 22.59%

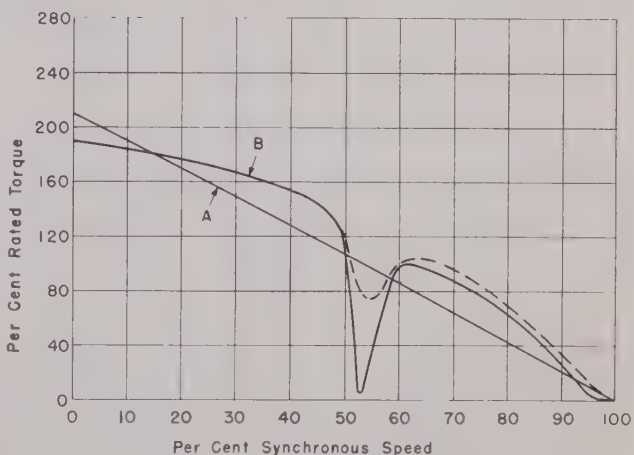


Fig. 11. Curve A: Theoretical curve for total resistance of 47 per cent when balanced

Curve B:	Motor	External	Total Resistance
	3.8	+ 14.65	= 18.45% in leg 1
	3.8	+ 14.95	= 18.75% in leg 2
	3.8	+ 99.99	= 103.79% in leg 3
		Average	= 47.0%

The solid portion of this curve shows torque values with unbalanced resistance as calculated from 120-volt test values. The broken-line portion shows test values obtained at 220 volts

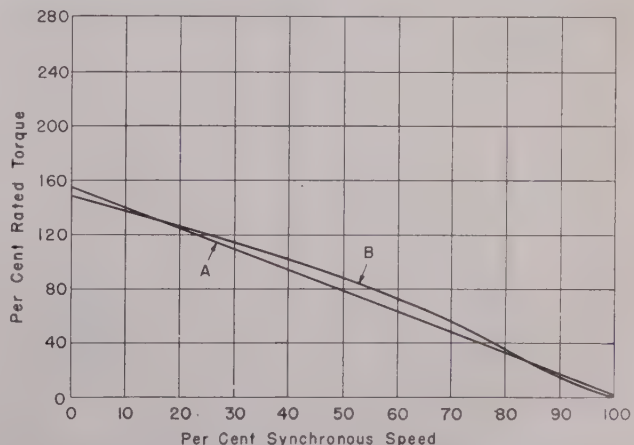


Fig. 12. Curve A: Theoretical curve for total resistance of 65 per cent when balanced

Curve B:	Motor	External	Total Resistance
	3.8	+ 17.18	= 20.98% in leg 1
	3.8	+ 62.00	= 65.80% in leg 2
	3.8	+ 102.20	= 106.00% in leg 3
		Average	= 64.26%

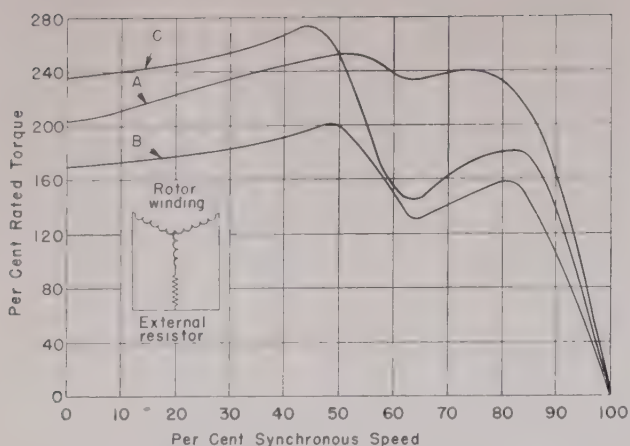


Fig. 13. Comparison of speed-torque characteristics of induction motor with unbalanced external resistance (resistor in one leg only)

Curve A: Average total resistance, 5.49 per cent
 Curve B: Average total resistance, 7.12 per cent
 Curve C: Average total resistance, 8.76 per cent
 (Details are given in first grouping, Table I)

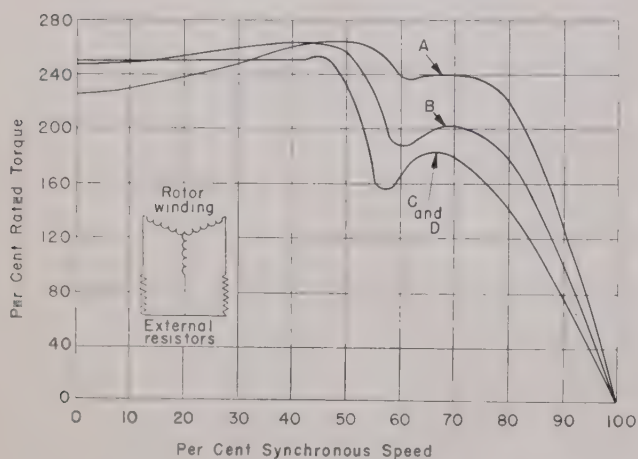


Fig. 14. Comparison of speed-torque characteristics with unbalanced external resistance grouped in two legs of rotor circuit

Curve A: Average total resistance, 7.12 per cent
 Curve B: Average total resistance, 10.49 per cent
 Curve C and D: Average total resistance of the two combinations, 13.61 per cent and 13.62 per cent
 (Details are given in second grouping, Table I)

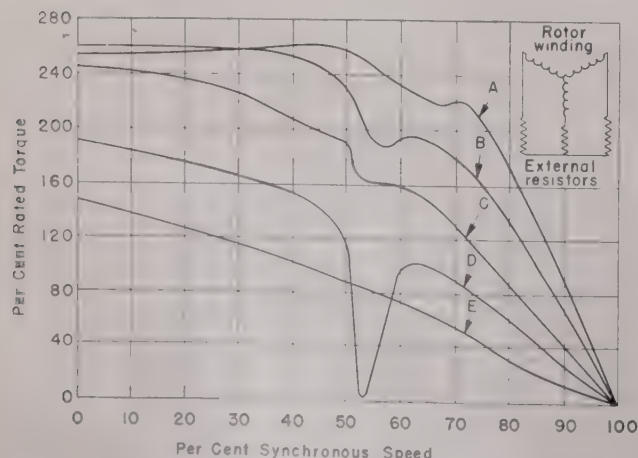


Fig. 15. Comparison of speed-torque characteristics with unbalanced external resistance in all three legs of rotor circuit

Curve A: Average total resistance, 10.76 per cent
 Curve B: Average total resistance, 14.63 per cent
 Curve C: Average total resistance, 22.60 per cent
 Curve D: Average total resistance, 47.00 per cent
 Curve E: Average total resistance, 64.26 per cent
 (Details are given in third grouping, Table I)

has approximately 100 per cent resistance in one rotor phase and 15 per cent in the other two phases. The broken-line portion of Curve B, Fig. 11 shows this speed-torque characteristic. This reduced torque dip at 220 volts as compared to the dip at 120 volts, but calculated for 220 volts, is apparently caused from the magnetic saturation of the iron when the oppositely rotating rotor magnetic fields cross at this critical speed.

Comparisons of Performance

Figs. 13, 14, and 15 show the data plotted in Figs. 3 to 12 inclusive, but the curves are grouped differently. All the speed-torque curves that were taken with several ohmic values in only one rotor leg (Fig. 1) are shown in Fig. 13 to present a direct comparison of torques as the external resistance is varied from approximately 5 to 15 per cent ohms. It will be noted that contrary to what one might expect, the 15 per cent value (Curve C) gave more torque than did the 10 per cent resistor (Curve B). Fig. 14 shows all the speed-torque curves that were taken with resistances in only two of the rotor legs (Fig. 2). These curves are related as would normally be expected. Fig. 15 shows all the speed-torque characteristics where there were resistors in each of the three rotor legs.

Conclusions

From this presentation of data several general conclusions particularly useful to designers of resistors are drawn for applications of this type. During the accelerating period of a motor, the speed will cover the entire range from zero to the running value. The required torque will very likely be a value between rated and twice rated torques. The several speed-torque curves show that, where the resistors are greatly unbalanced, the motor torques at about 60 per cent speed may dip sufficiently to slow up the rate of acceleration (for example, see Curves C and D in Fig. 4). Curves B in Figs. 6 and 7, and Curve B in Fig. 11 which correspond to various single, two-legged, and three-legged resistor combinations). However, since the motor should not be expected to run at a torque that exceeds rated torque, there was only one resistor combination (Curve B, Fig. 11) that produced a torque below rated torque in the regulating range. This combination was the one that most closely approached the open-phase condition in the rotor. It is of special interest to note that the last resistor combination listed in the third group of Table I, which had wide variations in each of the rotor phases, produced a very acceptable speed-torque characteristic (Curve B, Fig. 12). This would seem to indicate that if the rotor resistance were so designed that each point is equally unbalanced such as combinations represented by Curve B in Fig. 9, Curve B in Fig. 10, and Curve B in Fig. 12, then the torque dips are not very pronounced.

It should be noted that if a manual controller shorts out one section of resistor per point of the controller

(Fig. 16) in each rotor leg and if each third point provides a balanced resistance value, then the 3d, 6th, 9th, etc., points will provide the maximum unbalanced conditions as illustrated in the solid portion of Curve B in Fig. 11. If the controller has only seven points, the condition of maximum unbalance will occur in the 3d and 6th points of the controller (Fig. 16). However,

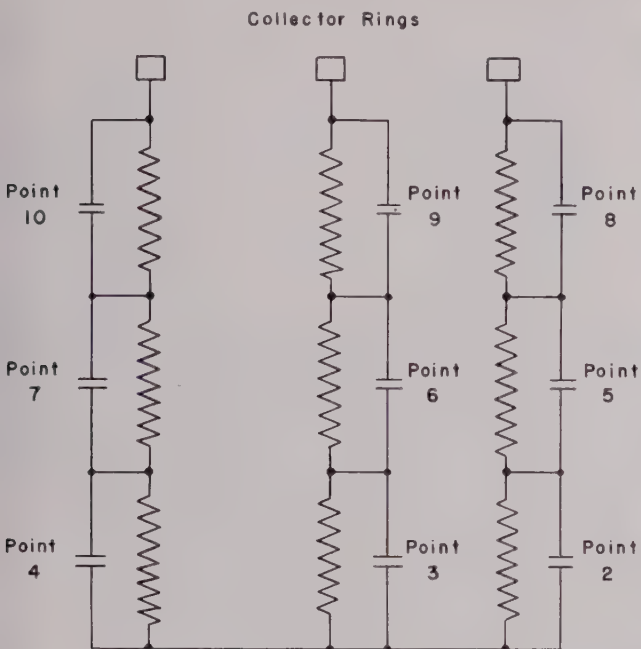


Fig. 16. The sequence commonly used when resistance is short-circuited from the rotor circuit of an induction motor by means of a manually operated controller. The first point is provided when the stator circuit is energized; other points are established in the order indicated

if the controller has ten or thirteen points instead of seven then the degree of unbalancing is not likely to cause any appreciable torque dips in the 60 per cent speed region. The seven-point controller characteristic can be appreciably improved by having an equally unbalanced resistance condition on every controller point except the last, or "all-resistance-shortened," position. This will result in a minimum unbalanced condition for any one point.

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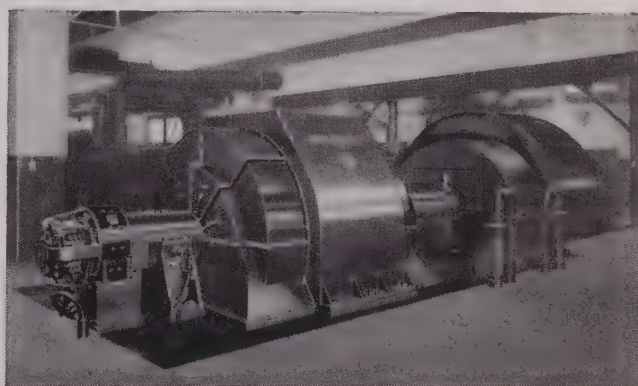
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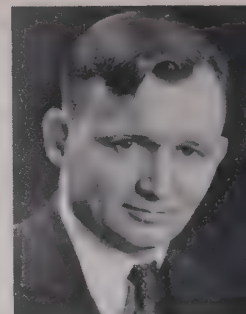
TO ELECTROLYSIS



E. W. Balis

Electrolytic targets as a means of protection, problems of geometry and chemistry associated with their use, and results of investigations

By DR. E. W. BALIS and DR. H. A. LIEBHAFSKY
Research Laboratory, General Electric Company



H. A. Liebhaufsky

THE larger electronic tubes such as power rectifiers must be cooled to remove the heat generated internally during their operation. When a potential difference exists across insulated sections of cooling systems that employ liquids, the coolant carries direct current as it flows through these sections, the circuit being completed through the metal parts of the installation. The metal at the anodic, or positive, end of an insulated section is therefore liable

to electrolytic attack. Electrolytic targets present problems in geometry and in chemistry, the latter being the more complex. The results of some of the work on both types of problem will be presented. Although this work was done primarily with power rectifiers in mind, the results may prove helpful also in connection with radio transmitter frequency changers, synchrotrons, and other installations that have cooling systems liable to electrolytic attack. All the present tests were done by making observations and measurements on metal electrodes (the targets) immersed in a solution (the coolant) carrying direct current.

Tests on Geometry

Depth of Immersion

For laboratory measurements on the distribution of current between target and piping, it is desirable to choose a simple arrangement, even at the risk of deviating from field practice. Fig. 2 shows schematically the

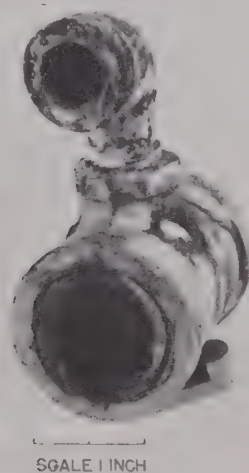


Fig. 1. Perforation resulting from electrolytic attack. The end of the insulating pipe projects from the front of the tee, which was anodic

to electrolytic attack which may eat the metal away at a rate sufficient to cause eventual perforation unless preventive measures are taken (Fig. 1). One such preventive measure is to connect to the anodic piping a metallic electrolytic target that projects into the insulated section and collects enough of the current so that the proportion leaking past the target to the piping does negligible damage.

For every metal anode in a cooling system, there exists a corresponding metal cathode. Since there is usually no damage at a cathode (where metal tends to be deposited, not eaten away), cathodic targets are not required.

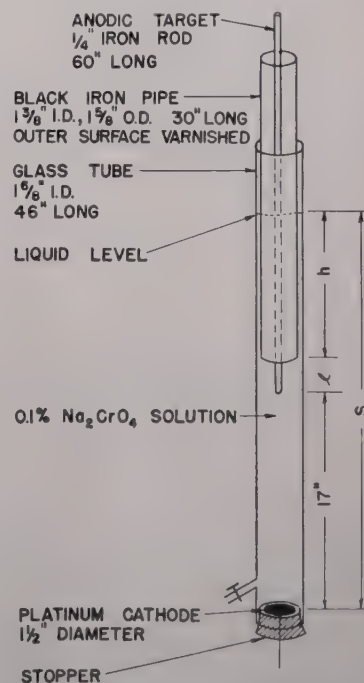


Fig. 2. Schematic diagram of apparatus used in measuring current distribution between piping and electrolytic target for variable depths of immersion and projecting lengths of target

This article is so paved that, without contributing other articles, it can be readily removed for film as a group of pictures consecutive pages.—Ed.

apparatus chosen. Since great precision was not needed, the heat generated in the solution by the passage of current was not removed.

The apparatus shown in Fig. 2 differs from an actual system in that the length of piping in contact with the electrolyte is much shorter. Consequently, it was desirable to see how the current distribution between target and piping varied with the depth of immersion; this was done by measuring the currents to pipe and target for various values of h (the depth of pipe

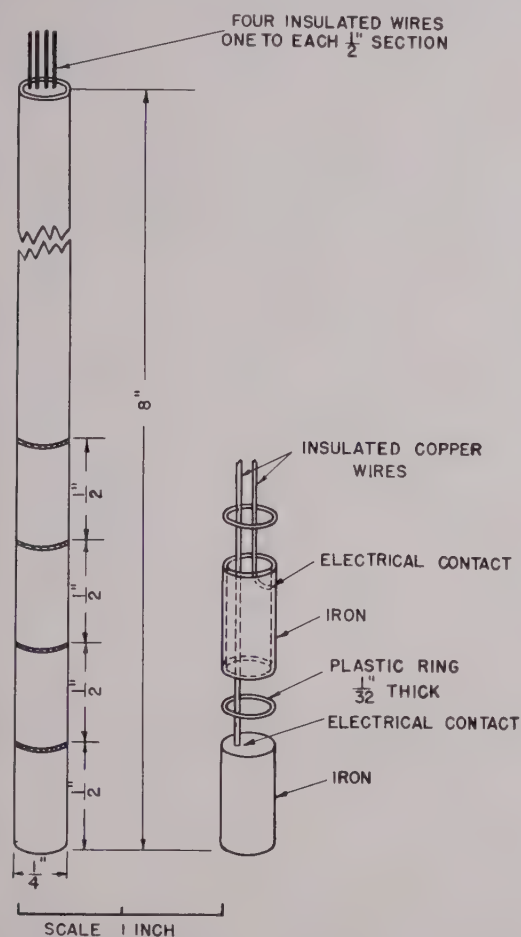


Fig. 3. Sectional electrode for measuring current distribution

immersion) at certain values of l (projecting length of target). Note that the depth of immersed target in Fig. 2 is proportional to that of immersed pipe, which means that the target receives some current that would go to the pipe were only the projecting length of target effective. Results for $l=0$ in. and $l=4$ in. are given in Table I.

In Table I, the distribution of current between pipe and target is virtually independent of h , the depth of immersion. The fact that depth of immersion influences the current distribution so little simplifies application of the results to field problems.

Current Distribution and Projecting Length of Target

Table II summarizes distributions of currents for five values of l . Each distribution is based upon a series of measurements analogous to those in Table I.

TABLE I
CURRENT DISTRIBUTION WITH VARYING DEPTH OF IMMERSION

Projecting Length of Target, $l=0$ inches						
Depth of Immersion h (inches)	Pipe Current (ma)	Target Current (ma)	Sum of Currents (ma)	Total Measured Current (ma)	Current Distribution (percent)	
					Pipe	Target
24	50.6	9.2	59.8	60.0	85	15
20	51.2	9.0	60.2	60.3	85	15
14	51.2	9.0	60.2	60.6	85	15
10	52.6	8.9	61.5	61.0	86	14
6	52.4	8.5	60.9	61.0	86	14
4	52.2	8.6	60.8	61.0	86	14
2	52.3	8.7	61.0	61.0	86	14

Projecting Length of Target, $l=4$ inches						
20	0.9	60.3	61.2	60.7	1	99
16	0.9	59.9	60.8	61.0	1	99
8	1.0	62.1	63.1	62.7	2	98
4	1.2	62.1	63.3	62.8	2	98
0	1.2	62.4	63.6	62.8	2	98

These data indicate that, for pipe of $1\frac{3}{8}$ in. ID, a target $\frac{1}{4}$ in. in diameter that projects 8 in. is satisfactory. For other cases, Table II may serve as a guide, as will information obtained with the sectional electrode described later.

Current Distribution Along a Projecting Target

Electrolytic attack that increases with current density is to be expected on most anodic targets. For this and other reasons, it is desirable to know the current distribution along a projecting target. Although it is possible in principle to calculate this distribution, it seemed simpler and more certain to construct a sectional electrode (Fig. 3) along which the distribution could be

TABLE II
CURRENT DISTRIBUTION FOR VARIOUS PROJECTING LENGTHS OF TARGET

Projecting Length of Target, l (inches)	Pipe Current (ma)	Target Current (ma)	Total Measured Current (ma)	Current Distribution (percent)	
				Pipe	Target
0	52	9	61	85	15
2	7	54	61	11	89
4	1	60	61	2	98
8	0.08	61	61	0.1	99.9
12	0.07	61	61	0.1	99.9

words, the presence or absence of piping has little effect on the current distribution over the front half of target that projects three inches or more.

Cooling systems in which electrolysis occurs are usually subject also to atmospheric corrosion. Both these processes are fundamentally electrolytic, but are assumed to proceed independently, as they probably do. In the case of atmospheric corrosion, potential differences arise and currents flow owing to conditions, such as differential aeration, inherent in the system. Electrolysis, as here defined, results from an imposed electromotive force.

An important practical relation arises between the two processes when an inhibitor against atmospheric corrosion is added to the coolant. Such an inhibitor, or its decomposition products, will usually decrease the resistivity of the coolant. The rate of electrolysis, which is proportional to the current flowing through the coolant, is consequently increased. Chromate, for example, is one of the best corrosion inhibitors, and it (dichromate) has an excellent record in the earlier power rectifier applications.^{(1),(2)} But the resistivity of 0.1 per cent aqueous Na_2CrO_4 (700 ohm-cm at 25 C.) is only 1/1000 that of good distilled water. Adding the chromate to such distilled water thus entails an enormous increase in the current carried by the coolant, and the consequent drawbacks are the price that must be paid for obtaining protection against atmospheric corrosion in this system. The least serious of these drawbacks

Fig. 4. Current distribution along the sectional electrode for varying tube diameters

The results of the measurements are given diagrammatically in **Figs. 4 to 6**, in which scale drawings of the electrode serve as abscissas. The height of each block represents the proportion of total current to each section; that is, current densities are not represented, and the current to the tip is included in the first block.

The figures are largely self-explanatory. Note that nothing corresponding to the piping in **Fig. 2** appears in **Figs. 4** and **5**; therefore, no current could have leaked past the target in these tests. In the experiments for **Fig. 6**, a platinum anode ring was used to simulate the pipe. The current collected by this ring could have been predicted roughly from Table II. Comparison of **Figs. 5** and **6** shows that this current is taken mainly from the long section of target nearest the anode ring, since the sum of the current to this section in **Fig. 6** and the current to the ring exceeds very little the current to the long section for the comparable case in **Fig. 5**. In other

Fig. 5. Current distribution along the sectional electrode, for varying depth of immersion; tube diameter, $1\frac{7}{8}$ in.

the power loss that must be accepted so long as the current flows. Obviously, chromate could not be used in an installation unless appreciable current in the cooling system can be tolerated.

Atmospheric corrosion will not be discussed further in this article. Even the problems involved in electrolysis are too complex for thorough treatment and it will be possible only to describe the behavior of a few representative target materials.

At anodic targets in an aqueous coolant, the two types of reactions most important for our purposes are, for example:

Oxidation of the target, $M = M^{++} + 2E$ (1)

Oxidation of water, $H_2O = 2H^+ + \frac{1}{2}O_2(\text{gas}) + 2E$ (2)

Here M represents the target metal; E, an electron. At the corresponding cathode, the usual reaction will be, for example:

Reduction of water, $2H_2O + 2E = 2OH^- + H_2(\text{gas})$ (3)

The rates of Reactions (1) and (2) will be determined by conditions at the anode; in the simplest case, the reaction requiring the lowest potential difference as driving force will proceed to the virtual exclusion of all others. If, for example, the target is made of platinum, which is very difficult to oxidize, practically all the current to the target will be consumed in producing oxygen.

On the other hand, if a copper target were to be used in a coolant containing chromate, almost all the current will go to oxidize the copper, little or no oxygen being liberated. Antifreezes or corrosion inhibitors may enter into anode or cathode reactions. In the ideal situation,

all the electric current will be active in the decomposition of water (the sum of Reactions (2) and (3)). The targets will then last forever, and the small amount of water consumed can be replaced at convenient intervals.

A few tests at room temperature, chosen because they illustrate these considerations, will be described in the following.

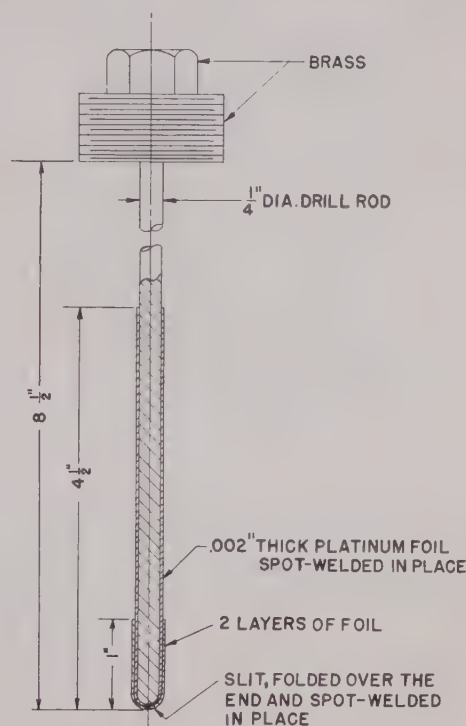


Fig. 7. Platinum-clad target

Platinum

Platinum, being an inert metal, qualifies as a satisfactory target material under all conditions likely to be encountered. For the purpose of economy, platinum-clad targets such as the one illustrated in Fig. 7 may be used. That target requires about 0.12 oz of platinum, the present price of which is about \$70 per oz.

Other noble metals would no doubt make satisfactory targets. Graphite would seem to be a good target material because it is inexpensive and relatively inert, but graphite rods of spectrographic purity used as anodes in tap water disintegrated rapidly at current densities near 0.3 amp per sq in.; both chemical and mechanical factors appear to be involved in the attack.

Platinum anodes are sometimes attacked at high current densities. To determine whether such attack would occur at an average current density of 4 amp per sq in. with chromate present, the two following experiments were performed: (1) A 40-mil platinum-wire anode was immersed two inches in an electrolyte of aqueous Na_2CrO_4 , 0.1 percent by weight, at a temperature of 45C. A current of one ampere was maintained for 236 hours. A slight reddish yellow precipitate containing no platinum formed on the anode. (2) A duplicate test was

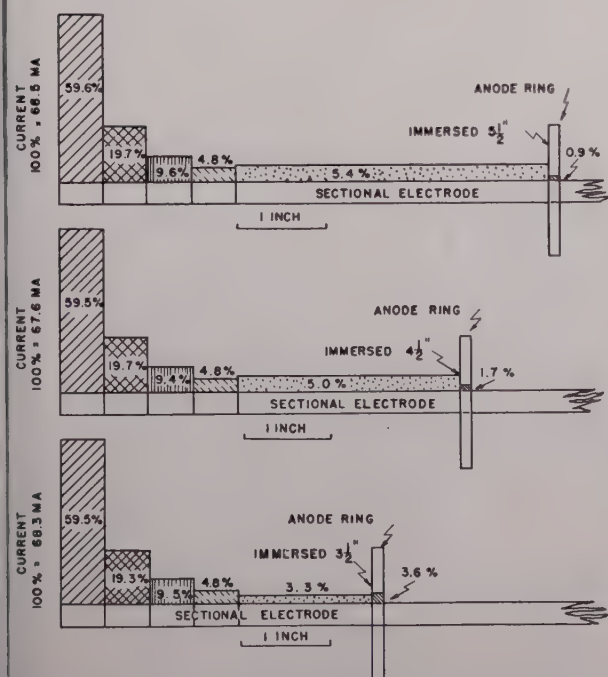


Fig. 6. Current distribution along the sectional electrode, with conditions as in Fig. 5, but with the addition of a separate anode ring

applied to the same anode for 194 hours, and there was little or no deposit on the anode. In these experiments the platinum was not measurably attacked; there was no appreciable change in weight of the clean platinum anode in either case, and no indication of corrosion of the surface could be found on microscopic examination. (The slight anode deposit derived from a trace of impurity in the solution.)

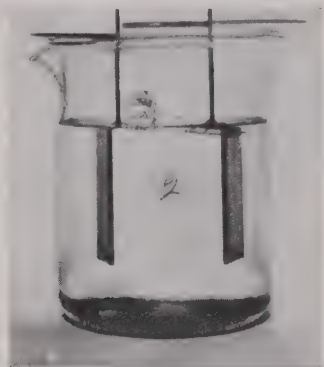


Fig. 8. Iron electrodes in 0.1 percent sodium chromate. Operated 240 hours at a current density of about 35 ma per sq in.

Iron

When sodium chromate solution is electrolyzed between iron electrodes, cathode and anode both become covered by protective films. As a result, iron, which ought to be attacked at the anode (Reaction 1), and chromate, which ought to be reduced at the cathode, are affected very little at low current densities. In other words, most of the current goes to decompose water because the protective films on the electrodes tend to make the iron effectively a noble metal. These conclusions are supported by Fig. 8 and by much other available evidence, as yet unpublished. In Fig. 8 the electrodes are in excellent condition, though a small amount



Fig. 9. Platinum-clad targets (left) and iron targets (right) after 45 days of service in a laboratory system with 0.1 percent sodium chromate solution as coolant and a current of about 0.3 amp. The lefthand member of each pair is an unused electrode

of an iron compound, presumably formed in anode attack, can be seen at the bottom of the beaker.

Under mild conditions, iron is thus a good anode target material when the coolant contains chromate as a corrosion inhibitor. Under more drastic conditions, attack of the iron is to be expected; iron will never be quite as resistant as platinum. The latter statement is illustrated by the two pairs of targets in Fig. 9. The right-hand target in each pair had been used for 45 days in a laboratory system with 0.1 percent sodium chromate as coolant, the currents being 0.3 or 0.4 amp. The used iron target is visibly attacked at its tip; it lost 600 mg during the run, while the clean platinum-clad target, which was unattacked, seemed to gain 5 mg.

Stainless Steel (18-8)

Since stainless steel is covered by a tough, invisible oxide film that renders it immune to attack under many conditions, one might expect it to be an ideal target material. It is of course susceptible to pitting if the coolant contains chloride.



Fig. 10. Stainless steel (18-8) electrodes in 0.1 percent sodium chromate. Operated 240 hours at a current density of about 35 ma per sq in.

There are other conditions under which it will not give satisfactory service. For example, the heavy deposit shown in Fig. 10 was derived from anode attack. Comparison of Fig. 10 with Fig. 8 reveals at once that stainless steel is far inferior to iron as an anodic target material when the coolant contains chromate. Fig. 11 shows that stainless steel is also unsuitable in an organic coolant (60 percent ethylene glycol—40 percent methanol by weight) that contains no chromate.

Fig. 12 shows two cells with stainless steel electrodes operated in series with distilled water and Schenectady tap water as electrolytes. In distilled water, the anode lost 20 mg; in tap water, 90 mg. These weight losses, if assumed to be iron, correspond to 0.8 percent and 3.5 percent of the total amount of electricity (8400 coulombs) passed in the experiment*. In the experiment shown in Fig. 11, the corresponding proportion was 1 percent. The well-known tendency of chloride ions

* The amount of chemical reaction produced by the passage of a given amount of electricity is governed by Faraday's Law. For example, in the experiments, twice 96,500 coulombs would have been required to oxidize one gram-atom of metallic iron to the ferrous state.

penetrate protective films was no doubt principally responsible for the increased anodic attack in tap water.

Stainless steel should prove a satisfactory target material in distilled water, for the resistivity of this coolant is so high that anodic attack corresponding to a few percent of the small currents flowing could be tolerated. Since distilled water is easily contaminated, a clean cooling system and occasional changing of the water are highly desirable.

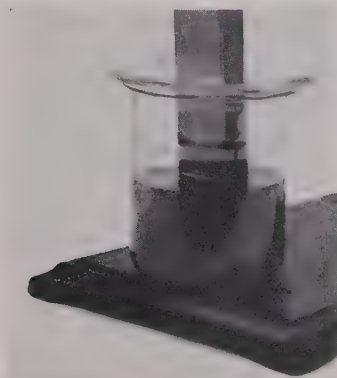


Fig. 11. Stainless steel (18-8) electrodes in 60 percent ethylene glycol—40 percent methanol (by weight). Operated 41 hours at a current density of about 3 ma per sq in.

The anodic behavior of stainless steel in different coolants illustrates the complexity of the cooling-system problem. Target behavior depends on many variables, the more important being: composition of target and piping; conditions at the surface of each; composition, resistivity, and temperature of the coolant; and current density on the target. We believe that platinum or platinum-clad targets can be safely recommended in all cases, and that they will usually prove most economical in the long run. Another metal can be soundly recommended only when the cooling-system problem is seen and understood as a whole.

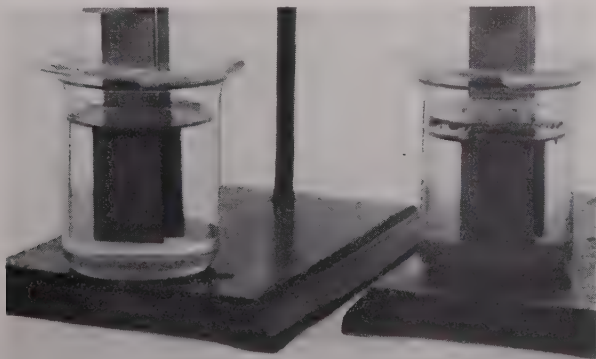


Fig. 12. Stainless steel (18-8) electrodes in distilled water (left) and tap water (right). Operated 19 hours at an average current density of about 65 ma per sq in.

Acknowledgment

The authors wish to acknowledge the assistance of Miss M. E. Kershaw and L. B. Bronk in the experimental work upon which this article is based.

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HIGH LIGHTS and SIDE LIGHTS

Toward Lightning Control

Hoping to make new inroads in the battle against man's most elusive natural foe, scientists are completing their eighth summer of lightning research high atop New York's Empire State Building. A continuation of research begun in 1935, the work will go on until October 1.

Complete photographic records and electrical measurements have been obtained during the summer on all lightning strokes striking the National Broadcasting Company's antenna atop the building.

By scientific analysis of such records, new information will be gained which will contribute further to the control of the effects of lightning. Such information also will be useful for application in the laboratory, where artificially produced lightning can be used to test electrical apparatus.

By addition of new photographic equipment, strategically located, and improvements on sensitive recording devices, the engineers expect to determine the exact currents in each lightning stroke, the length of time each stroke lasts, the intensity of the light produced by the lightning bolt, and the physical shape or path of the stroke.

A heavy copper cable extending through the interior of the National Broadcasting Company antenna atop the building receives the lightning impulses and carries them to oscillographs in the attic, where the currents and time lengths are recorded. Simultaneously, photographs of each stroke are taken from two different locations at right angles to the building. Thus, a three-dimensional view of the stroke is obtained and its exact length determined.

An "electronic brain," an automatic corona device mounted on the top railing of the building, acts as a storm "watchman," turning on all recording equipment as storms approach the city or as storm fields form around the building. The operator thus need not be on hand immediately to gather data. The device can be made so sensitive that a heavy fog may start the recording machines.

A high-speed camera and a low-speed multiple-aperture camera, set up north of the building, are designed to take as many as 20 photographs with a single loading of film. A third camera, called the "oblique camera," is located west of the Empire State Building. A low-speed movie-type instrument taking a frame every minute, this camera photographs each stroke at a right angle to the exposure field of the other two cameras. The motor which runs this camera can be started by a remote-control telephone device.

To determine the opaqueness of the air—the cloudiness caused by rain, fog, smoke, or other foreign material—a light of known intensity is reflected by a parabolic mirror to a photoelectric cell at the camera location north of the building, where the brightness of the light is recorded. This record is used as a comparison, so that the engineer gathering the lightning data can evaluate more accurately the intensity of the lightning stroke.

Bit-weight Control for Oil-well Drilling

An electric device has been developed which, from above ground, automatically controls the weight of an oil-well drilling

bit operating 18,000 ft beneath the earth's surface.

Known as the "bit-weight control," the device "feels" the weight of the heavy, underground drill stem and adjusts the position of the hoisting mechanism to maintain a constant restraining force on the drill stem. The actual weight on the drill is thereby reduced to an allowable force.

The control device is expected to speed drilling operations by minimizing the number of times the entire drill stem must be brought to the surface for replacement of worn-out drilling bits. The process of raising this long stem takes several hours.

The weight of a 15,000- to 18,000-ft-long drill stem could put 400,000 lb of force on the bits. This is far above the allowable force and must be decreased by tension on the drill stem. By controlling that tension, the bit-weight control eliminates excessive wear on the drill's cutting edges and bearings.

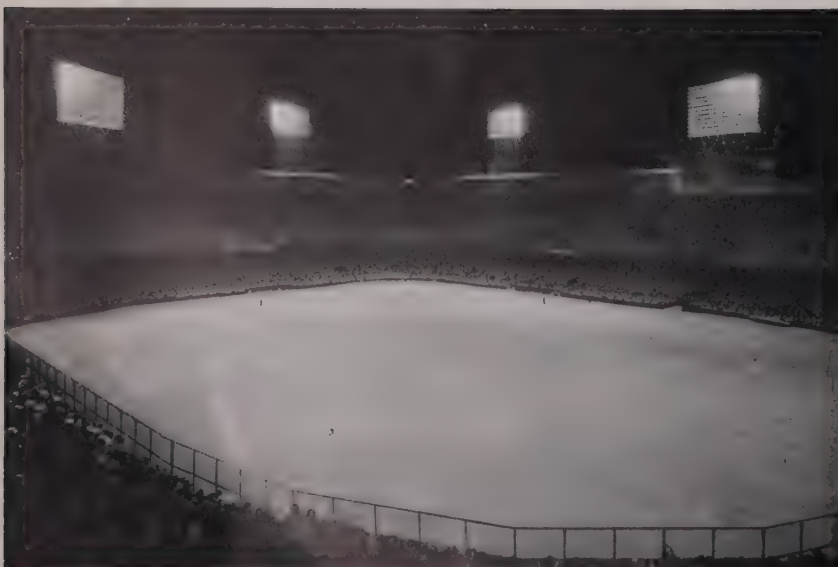
In operation, the device receives electric "messages" from a small generator which indicate whether too much or too little tension is being exerted on the drill stem. The position of the hoisting mechanism then is changed automatically to permit the drill to function under the most efficient pressure. At an average drilling depth, the control is accurate to within a small percent of the total force.

World's Most Brilliantly Lighted Ball Park

Briggs Stadium, home of the Detroit Tigers, became the world's most brilliantly lighted baseball park this summer when 1386 newly installed floodlights were snapped on for the first major league night game in the city's history.

Mounted on eight towers around the field, the floodlights provide illumination of 182,000,000 cp, which is equivalent to the light from 24,000 one-hundred-watt reading lamps or from 6000 full moons. The prefabricated steel towers, of cantilever construction, rise approximately 150 ft above the ground.

The installation puts Briggs Stadium into the "big three" of lighted baseball parks with Yankee Stadium, New York, and Fenway Park, Boston. All three of these parks have nearly twice the illumination of any other playing fields in the United States.



Briggs Stadium, home of the Detroit Tigers of the American League, where night games are now played in better light than is available in the average office

The Stadium's 2,500,000-watt floodlighting system will project enough light to illuminate a superhighway from New York to Buffalo. The lights have been designed mathematically to provide an even light level of more than 200 ft-c in both the infield and outfield. A man seated on second base would find eight times more light in which to read his newspaper than he would in his easy chair at home. Some 10 times more light will be afforded the ball players than is available on the desk top of the average office worker.

The door glass of the floodlights used in the installation is made of impact-resistant, tempered glass which has withstood repeated blows from thrown baseballs without shattering.

Fifty-eight one-thousand-watt and 1328 fifteen-hundred-watt floodlights comprise the installation. The lamps of both types are sealed against weather, dirt, and insects to assure dependable performance.

Fingerprints by Electronics

Facsimile, the art of delivering "electronic newspapers" over radiowaves, recently has been used to send reproductions of fingerprints and of other materials from point to point.

The transmission, carried on for members of the New York State chapter of the Associated Police Communications Officers, was believed to be one of the first public uses of facsimile for this purpose.

Used for the demonstration was a new radio frequency, which carried facsimile for the first time—920–960 megacycles, a channel set aside by the Federal Communications Commission for miscellaneous users of point-to-point communication.

Although the trial transmission extended only a quarter of a mile between two buildings, fingerprints, photographs, and other police information could be sent by facsimile as far as about 50 mi. Higher antennas would materially extend this range.

This application of facsimile was seen by the visiting police communications officers as an aid to rapid apprehension as well as elimination of some of the usual bottlenecks connected with holding captured criminals. In many states, criminals cannot be held longer than 20 hours.

It may pave the way for central record-keeping bureaus whence facsimile messages could be exchanged with other stations in a matter of seconds. The central station could send, via facsimile, photographs, signatures, Bertillon data, and other civilian and criminal information. These data would furnish positive identification information immediately and could not have to be processed photographically.

Equipment used was manufactured by Radio Inventions, Inc., and sold to a



APCO officer examines fingerprints as the reproductions come out of the facsimile receiver

number of newspapers who are experimenting with facsimile as a method of news dissemination.

Following this demonstration, facsimile is expected to find widespread application in police work.

New Uses for "Useless" Elements

Rare chemical elements, some of which were recently thought to be useless, are finding an increasing number of important applications in science and industry today. This fact was brought out recently in a broadcast of the Science Forum, over station WGY, Schenectady.

Uranium was cited as an example: a decade ago this element was used commercially "only in small amounts for a few odd jobs such as coloring of glass and china." Since then uranium has become of paramount importance in the development of atomic energy.

Polonium, a radioactive element so rare that the quantities used can hardly be weighed and are invisible to the naked eye, is now used to dissipate potentially dangerous static electricity. Radiations from polonium, harmless to humans, turn the surrounding air into an electrical conductor, and the static leaks off as it is formed. Easily plated on other metals, polonium can be used effectively in small quantities.

Tiny crystals of germanium, an element on the chemical borderline between metals and insulators, it was explained, act as rectifiers; that is, they change alternating current to direct current. This property of germanium made the element extremely important in radar work during the war, and applications have been found in the

high-frequency radio work common today in television, FM, and commercial radar.

Another of the rare elements described was indium. Once displayed before chemistry classes as a classical example of a metal for which no one had any conceivable use, indium is now used in corrosion-resistant bearings.

Photographs at High Speed

New high-speed photographic equipment has been developed to catch the image of objects moving far faster than sound.

A flash of light lasting only 0.000002 sec throws enough bright light on exceedingly quick action to take photographs showing virtually no motion. A camera, with its shutter open, is placed with the light source in a dark room, where the action is to take place.

The new flash unit will enable engineers to study more accurately the properties of objects moving at high velocities.

A naval shell in flight at 1842 mph, more than twice the speed of sound, moved only 0.065 in. during the two-microsecond exposure when photographed with the newly devised equipment. The shell set off the flash and took its own picture by cutting between a beam of light and an "electric eye."

The flash unit is said to give light of a higher intensity than previously available high-speed light sources. The light comes from an electrical discharge through ionized argon, an inert gas. The lamp is placed in the focus of a parabolic reflector, which directs the bright light in parallel beams.

(Concluded on next page)

The light-source equipment consists of two boxes slightly larger than shoe boxes, one containing the light source itself, the other containing controls. Synchronization of the flash with action to be photographed depends upon the nature of the subject. The control box is so constructed as to make a variety of signals possible for setting off the lamp. Among these are: the making or breaking of a light beam; a signal from a crystal microphone, whereby sound may trigger the flash; a manually operated push button; and the making or breaking of electrical circuits.

Clear As Mud

An absent-minded printer spoke recently for millions of atom-bewildered citizens while setting type for a General Electric Company handbook on nuclear physics. A page describing giant atom-smashers carries a boldface headline, UNCLEAR PHYSICS.

Electric Stimulus for Muscles

Paralyzed muscles can be stimulated with electric current and thus prevented from wasting away through disuse, by means of a new instrument which was

demonstrated recently at the First International Polio Conference in New York.

Known as a variable-frequency wave generator, the device was said to be useful in almost any type of paralysis, with practically no discomfort to the patient.

Acting as a "substitute nerve," electric current from the instrument alternately contracts and relaxes paralyzed muscles, thus giving the muscles the benefit of prolonged exercise without effort on the part of the patient. When possible, paralyzed muscles can be made to work against a resistance, such as a weight or spring tension, resulting in vigorous muscle exercise.

Treatment is so easily tolerated that young children often play unconcerned while their affected muscles are being exercised.



Paralyzed muscles of a little girl are artificially exercised by the new muscle-stimulating device, which uses electric current to contract and relax paralyzed muscles and thus prevent them from wasting away through disuse

Considerable experimentation with the device has revealed that the wide range over which the frequency may be varied makes the new machine ideal for use on either totally paralyzed or partially paralyzed patients. The range runs from 2 to 6000 cycles per minute, making it possible to vary the frequency to the level which is best tolerated by the patient.

The frequency range also makes it possible to hold the intensity of the current to a minimum, thus permitting stimulation with little or no discomfort and with no skin irritation by electrodes through which the current is passed.

The instrument permits a doctor to change the frequency without taking the patient out of the circuit, and when joints are painful, the muscle can be contracted without moving the limb.

In cases where patients have had effects of paralysis for six months to six years, evidence indicates that electrical stimulation may be of value in helping restore normal nerve patterns in the muscles involved. Such stimulation is now believed to help the patient gain a sense of muscle action, thus aiding in re-education of muscles when he attempts active exercise.

Simplified Recovery of Precious Powder

Equal in weight to two dozen gems the size of the fabulous Hope Diamond, 100 carats of diamond dust were recovered by one laboratory in 1947.

Fine and white as face powder in appearance, the diamond dust is used to polish dies of tungsten-carbide, one of the hardest compounds yet devised by man. The precious powder can be used over and over again, but recovery in the past has been difficult, for the diamond dust falls into a receptacle during the polishing process and mixes with oil, bristles, bits of cloth, and tungsten-carbide powder. The process developed during the war has simplified greatly the recovery operation which once required large quantities of acid and long periods of time to dissolve everything but the diamond dust.

By the new process, diamond-dust recovery is now a matter of hours rather than weeks, and the amounts of chemicals needed are negligible.

First of all, the chemist burns off the oil, cloth, and other combustible materials in the mixture on an ordinary hot plate and washes it, leaving only tungsten carbide and diamond dust. Then he washes the residue with concentrated hydrochloric acid, which oxidizes the tungsten. Tungsten is difficult to dissolve but by placing the mixed powders in a furnace at 800 C, he converts the tungsten oxide into tungsten trioxide, which is easily dissolved in a solution of sodium hydroxide (caustic soda). When the powders are washed with that chemical only the valuable diamond dust remains.

Weather Recorder

A portable "electric weatherman" which automatically and continuously records wind directions and wind velocities in remote, unmanned weather stations, has been developed for the U. S. Army Signal Corps.

The device is slightly larger than an infantryman's pack and requires attention only once a month. Time, wind speed and wind direction are marked continuously on a moving roll of paper which is long enough to make an 800-hour record.

The electric weatherman uses no ink in making its records. Moving arms, connected electrically to a conventional anemometer and to a weather vane, mark the specially sensitized paper by sending sparks through it.

The instrument can register wind velocities up to 150 mph and can read direction correctly within one and one-half degrees. The paper moves beneath the markers at three quarters of an inch per hour.

Three such instruments have been delivered to the Signal Corps.

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New!
Series 570-600
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Here is a new addition to the line of G-M galvanometers. It is a completely assembled unit featuring an Alnico magnet for greater stability of calibration and a new high in sensitivity. Easily installed and replaced, requires only 2 1/2" below the mounting surface. Rugged construction throughout. Three models, with sensitivities per mm. division of .06, 0.10 and 0.20 microamps.

Write for specifications and prices on these and other galvanometers

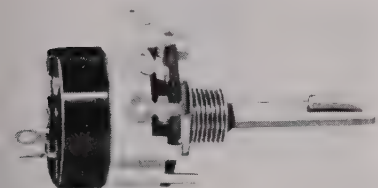
LABORATORIES, INC.

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NEW PRODUCTS: AND WHAT THEIR MAKERS HAVE TO SAY ABOUT THEM

Resistor

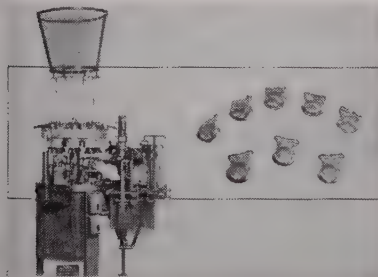
A $\frac{1}{8}$ -in. variable resistor named Midgeol has a new basic design, resulting in an extremely low mechanical and electrical noise level. Moreover, tests demonstrate that the unusually quiet operation is maintained after tens of thousands of cycles. In addition to its space-saving feature, the resistor has electrical characteristics which make it suitable for many applications previously requiring a $1\frac{1}{8}$ in. control.



One new feature is a flat shaft which is easily adapted to fit any type of knob now in use. Other design features include two-point shaft suspension; machine-coated carbon elements; strong hot-tinned terminals; fully insulated current-carrying parts; and special phenolic shaft for television applications.—*R. Mallory & Co. Inc., Indianapolis, Ind.*

Flare Machine

A new automatic prepressed flare machine successfully combines flare making and flare stretching. With a productive capacity of 2400 flares per hour the machine delivers the preformed flare without intermediate handling. The prepress attachment has 12 positions on the turret. This attach-



ment automatically picks up the flare at the setting position, which eliminates tumbling and track transfer and dispenses with cooling and reheating processes. Also, it is provided with either a stretching mechanism, a pressing mechanism, or both. Indexing is by barrel cam and roller, totally enclosed in oil the same as on the flare machine itself. The machine is adjustable for precise variations in diameter, length, press, width, press thickness, etc.—*Kahle Engineering Co., 1313 Seventh St., North Bergen, N. J.*

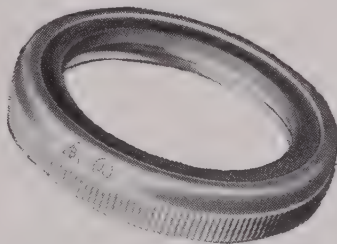
Vibrometer

A new recording vibrometer instrument, seven inches long and four inches wide, can be held easily in one hand. The instrument will be useful in investigating vibration problems in factory buildings, gears, motors, etc. A short metal prod, which is held against the vibrating object, protrudes from the side of the vibrometer. Inside the instrument's case, a moving sapphire point

rests on moving waxed-paper tape. Vibrations are transmitted through the prod, magnified 12 times by a spring, and passed on to the moving point, which draws curves showing the frequency and amount of vibration. A constant-speed electric motor moves the tape under the point, and makes a timing mark on the tape every three seconds.—*General Electric Co., Schenectady 5, N. Y.*

Metallic Bushings

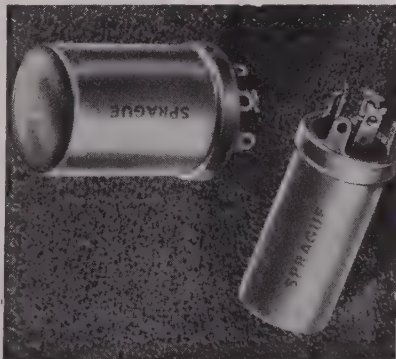
The new insulated metallic conduit bushings known as Bushends provide protection against abrasion of cable insulation and accidental grounds. One significant feature is that they require no inside locknuts. Although light in weight and low in cost, these bushings are so durable as to be practically indestructible. Their metal bases are fabri-



cated from an extremely tough corrosion-resistant wrought alloy of high mechanical strength. The threads are free, clean-cut and nonseizing, and the knurls are extra deep to facilitate tightening even in restricted hard-to-get-at places. The insulation, which is permanently and securely positioned in the metallic base, is exceptionally tough and has high dielectric strength and resistance to moisture absorption.—*Buchanan Electrical Products Corp., 2 West Jersey St., Elizabeth 4, New Jersey.*

Electrolytic Capacitors

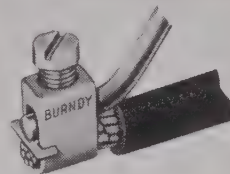
A new line of electrolytic capacitors designed specifically for television requirements. The new units are rated for dependable operation at 85°C up to 450 volts. They are the result of improved processing techniques and new manufacturing facilities. The new design and improved manufacturing techniques also result in units with extended shelf life.



With some seven times as many components in a television receiver as in the average radio, the possibility of service calls on sets still in warranty is greatly increased. This condition emphasizes the importance of dependable trouble-free electrolytic capacitors in all television circuits.—*Sprague Electric Co., North Adams, Mass.*

Conductors

By means of a new connector of the so-called Buttin type, copper and aluminum conductors can now be connected at service entrances. In fact, only the new type of connector is now needed to connect the following combinations of service-entrance wire:

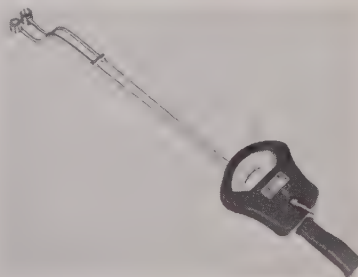


copper to copper; copper to aluminum; aluminum to aluminum; and aluminum to copper.

The tin-plated copper alloy body makes the connector suitable for both aluminum and copper. A pressure bar, also tin-plated, distributes the screw pressure so as to minimize cold-flow of the aluminum conductors placed beneath it.—*Burndy Engineering Co. Inc., 107 Bruckner Blvd., New York, N. Y.*

Content Indicator

A new portable solder tin content indicator, Model 2870, for quickly checking analysis of solder quality. It provides a means whereby manufacturers of metal containers can determine the ratio of the lead and tin content in solder for process standards and economy.



This instrument, which was developed in co-operation with Continental Can Co., consists essentially of a high-resistance pyrometer and dual thermocouple extensions: one with a lead container, the other one with a solder scoop. The meter movement includes baked processed coils, supported by two lapped pivots resting in highly polished sapphire jewels; and an alnico magnet, highly resistant to shock, heat, vibration, and stray fields. A $3\frac{3}{16}$ -in. wide mirrored scale is calibrated in divisions representing the percentage of the tin content of the solder.—*Wheelco Instruments Co., 847 W. Harrison St., Chicago, Ill.*

Plaster Guard

Plasterguard is the name given to a plate which is placed in the coverplate frame of outlet boxes, prior to plastering, to prevent plaster from getting into and hardening in screw holes and boxes. This plate eliminates the necessity of an electrician scraping and

NEW PRODUCTS (Continued)

cleaning boxes before completing final installation. It is estimated that use of these guards will reduce installation time from 15 to 30 min. They fit within the frame of the outlet box and are held there by four spring ears. These plates provide an efficient replacement for the outmoded method of stuffing newspapers into the box.—*O. Z. Electrical Manufacturing Co., 262 Bond St., Brooklyn 2, N. Y.*

Wiring Test Set

This wiring inspector's test set enables one person to make a complete test of the wiring in any building without additional help. The device is housed in a gray fiber carrying case measuring 14 9/16 in. long.



Total weight is 13 lb. A compartment provides storage space for the flexible leads and the portable meter. Power is supplied from a standard 6-volt dry cell, which can be easily replaced. All standard electrical component parts are used throughout.—*Eastern Specialty Co., Philadelphia 40, Pa.*

Grounding Wedge

This versatile grounding wedge for use with any standard conduit bushing can be readily slipped over existing wiring and so positioned that the screws are easily accessible. The larger of the two screws is the bonding screw which serves a dual purpose. First, when tightened on the bushing, it wedges the device securely in place and acts as a lock washer to prevent the bushing from vibrating loose; and, secondly, the screw when tightened bites firmly into the bushing to insure a permanent bond between box and conduit. The jumper screw, which is shorter, provides the connection when the wedge is used with "nested" or "concentric" knock-outs. These wedges are made of bronze to give strength, durability, conductivity, and a spring quality necessary for a continuous metallic path to the ground.—*The Thomas & Betts Co., Inc., Elizabeth 1, N. J.*

Woodworking Machine

A new all-purpose woodworking machine, Model GR, designed for precision production work, features a 3-hp motor for driving a 14-in. diam saw with a 4 1/4-in. depth cut. Technical improvements include a heavy-duty 8 ball-bearing roller travel head riding on machined tracks inside the arm and mechanical aligning adjustments at all moving positions to maintain accuracy. The design of the safety guard affords maximum protection. An adjustable dust spout directs the flow of sawdust. By using the proper cutting tool, this saw becomes either a dado, gaining, grooving, rabbeting, or shaping machine.—*DeWalt, Inc., 101 Martha Ave., Lancaster, Pa.*

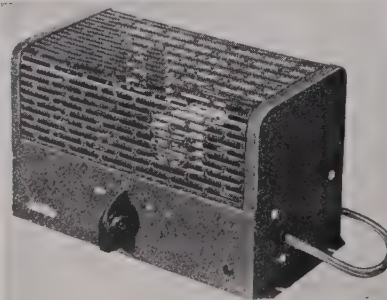
Half-load Relay

A new half-load relay designed to improve cold-weather starting of 10,000- and 21,000-lumen mercury-vapor lamps on series street-lighting circuits. When used with these lamps, this relay approximately doubles the useful load capacity of the constant-current transformer and eliminates the installation of an additional series circuit. Also, it permits a changeover from 400-watt, 16,000-lumen Type F-H1 lamps to 21,000-lumen mercury Type E-H1 lamps without adding constant-current transformer capacity.

The relay consists of a standard street-lighting controller and a time-delay relay; the element to operate the controller is housed in a waterproof casing with a hinged door for easy accessibility. A mounting strap welded to the casing permits either pole or cross-arm mounting.—*General Electric Co., Lighting and Rectifier Divisions, Schenectady 5, N. Y.*

Amplifier

A new booster amplifier Model D-29 for use with intercom and sound systems, to increase the power volume needed for adequate coverage of large or noisy areas. Offering a practical and economical answer to many heretofore unsolved acoustic problems, this new compact amplifier provides



increased paging volume on systems designed to call or page all stations simultaneously. When coupled with a standard reply station, this amplifier solves for the first time the problem of providing audible two-way intercommunication in very noisy locations, such as machine shops, press rooms, factory areas, etc.—*Executone, Inc., 415 Lexington Ave., New York 17, N. Y.*

Germicidal Lamp

A new 36-in. slimline-type germicidal lamp capable of operating at four different germ-killing intensities. When operated in air ducts or other places where moving air cools the tube, the lamp can be operated at its highest current rating to provide more ultraviolet germ-killing energy than any previous germicidal lamp. It can be used in conventional fixtures for upper-air protection of the occupants in a room; in ventilating systems at its highest electrical efficiency to kill germs in circulating air; and for many and varied industrial applications, such as protecting meat stored in coolers and protecting foods, cosmetics, and other products during the manufacturing process.

The lamp operates at 120-, 200-, 300-, and 420-ma; its rated life is between 2500 to over 6000 hr, depending on the average number of burning hours each time the lamp is lighted.—*Lamp Dept., General Electric Co., Nela Park, Cleveland 12, Ohio.*

Pilot Light

A new pilot light with a Multivue intended especially for the NE-51 neon glow lamp. A new principle is used in the cap of this pilot light. Instead of being scattered facets or concentrated by a lens, the light from the glowing electrodes is refracted



such a way that a multiple image is seen from any viewing angle. The necessary resistor for the neon lamp is built into the assembly, and is proportioned to the voltage and service to give the maximum satisfaction. Connections are made to binding screw terminals, or to soldering lugs which are optional. The lucite caps are made in a full range of jewel-like colors.—*The Dial Lamp Co. of America, Inc., 900 Broadway, New York 3, N. Y.*

Laboratory Stirrers

In both direct- and gear-drive types, the new laboratory stirrers have complete speed control and stainless steel mounting rods which permit them to be used on any standard laboratory support. Model 7605D is a direct-drive medium-powered stirrer for continuous duty in general laboratory work. It has a double housing, offering extra full protection. The 1/50-hp motor operates



with rheostatic speed control from 0 to 10,000 rpm.

Model 7605E has a 1/12-hp motor which equips it for the heavier stirring applications and makes it practical for many serious industrial jobs. A table-top rheostat controls the speed from 0 to 5000 rpm.

Model 7609C includes all the features of power, ruggedness, and durability, with the addition of reduction gears giving high torque at low speeds. The 1/18-hp motor has a high-speed shaft running up to 5000 rpm and a low-speed shaft to 833 rpm, with a maximum torque of 3.0 in.-lb. All operations on 110 volts, a-c or d-c.—*Palo-Myers, Inc., 81-83 Reade St., New York 7, N. Y.*

Axial-flow Pump

A large-capacity axial-flow pump designed to resist contaminated sea water and other corrosive liquids. The pumps are especially suited for condenser circulation and other services requiring low-cost high-speed pumping of large volumes of liquids. Im-



PELLERS and suction bells are cast of 25 per cent chrome and 12 per cent nickel stainless steel, and the pump shafts are 18-8 stainless. The column and discharge elbows are formed of a high-test cast iron containing approximately 2 per cent nickel. These axial-flow pumps are best fitted for applications where any variation in head is a reduction, and where the resultant increase in capacity is not objectionable. Most of these pumps are custom-built for specific jobs.—*Economy Pumps, Inc., Hamilton, Ohio.*

Transformer Cores

Horizontal deflection and flyback transformer cores molded from iron powders for television applications. These transformer cores assure uniform operating results while permitting easier assembly at a worthwhile cost saving. Two standard types are available: A large rectangular unit with sliding hub, No. 10034, is designed for universal use with any television tube from the smallest to



the largest where magnetic deflection is used; and a smaller "spool" type, No. 10748, is recommended where space is at a premium, and where tubes are no larger than 10 in.—*Electronic Components Division, Stackpole Carbon Co., St. Marys, Pa.*

Lettering Instrument

The Variagraph lettering instrument is a small mechanical device for reproducing many sizes of letters from a single templet directly in ink or pencil on any suitable

surface. The letters can be reproduced to any desired width combined with any desired height between 0.075 and 0.750 of an inch. Letter width and letter height are controlled by positioning two knobs.

The instrument rests directly on the surface being lettered and slides against any straightedge while being moved from one letter to the position of the next letter. A lettering templet carried by the instrument slides left and right to position the desired letter. To reproduce a letter, a finger-operated point follows the letter grooves in the templet. This instrument can be used with equal ease by either a right- or lefthanded person.—*Variagraph Co., Inc., Lincoln 3, Nebraska.*

Light-beam Wattmeter

A new light-beam wattmeter developed to meet industry's need for a portable, accurate instrument giving readings in the low-wattage, low-power-factor ranges for frequencies of 25 to 3000 cycles. The wattmeter's portable construction, high sensitivity, and low instrument losses make it applicable where conventional wattmeters and pivoted-type dynamometers operate under definite limitations.



It can be used in instrument-calibrating laboratories as a transfer wattage standard from d-c to a-c for the calibration of other wattmeters and in laboratory production testing for such devices as small reactors, relays, selsyns, fluorescent lamps, fluorescent-lamp ballasts, and core-loss measurements.

Full-scale wattage is indicated at power factors as low as 0.08, and 2 watts at 120 volts is sufficient to give full-scale indication.—*General Electric Co., Meter and Instrument Divisions, West Lynn, Mass.*

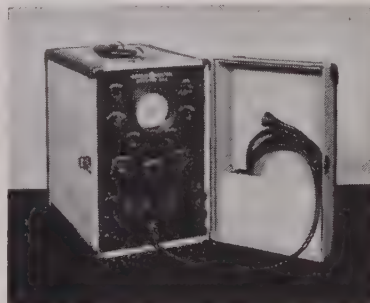
Carbide Bushings

A new line of standard all-purpose carbide bushings serve a multitude of uses as wear-resistant parts where either inside or outside diameter is critical. Various sizes of these bushings are already in use as fine yarn guides in textile machines, as wire guides, and as bushings and collets in Swiss automatic machines. They also can be adapted for valves and orifices in spray-gun nozzles; as plug-gage bushings, especially on extremely fine instrument work; on guide rolls and feed rolls; and as drill-jig bushings.

The bushings are available in two general size classifications. The bushings in Group A are relatively short, while those in Group B are comparatively thick and long. The small sizes in Group A are furnished in Carboloy Grade 883. The larger sizes in Group A and all bushings in Group B are furnished in Carboloy Grade 44A.—*Carboloy Co., Inc., Detroit 32, Mich.*

Oscilloscope

New industrial oscilloscope, Type YNA-4, designed specifically for service applications in the field of industrial electronics. Developed after a thorough survey of industrial designs and maintenance engineers, the "scope" is intended for servicing such equipments as resistance welders, motor control circuits, power supplies, and photoelectric circuits.



The scope has a three-inch tube with sufficient sensitivity to expand the trace to several times the tube size. The equipment includes push-pull d-c amplifiers of high sensitivity; high-and low-impedance vertical input with step and continuous attenuation, to handle wide range of signal input; horizontal sweep range of 10 cps to 20 kcps; internal source of d-c for deflection calibration; and a completely insulated case and panel permitting operation up to 550 volts above ground.—*General Electric Co., Electronics Department, Specialty Division, Syracuse, N. Y.*

Cable Protector

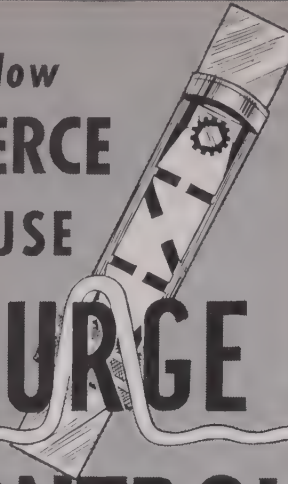
A new protective coating in an adhesive roll, called No-Ox-Id Wrap, developed to guard lead-sheathed cables in manholes from corrosion. This product combines two steps in cable protection: a corrosion-resistant coating and a sturdy wrapper. It eliminates separate applications, and is water repellent. Corrosion-inhibitive qualities provide a protective film to keep cable free from pitting. One man can apply it, simply by manually winding the wrap spirally, with a 1/2-in. overlap, directly around the cable. Uniform thickness promotes smooth coverage. A firm bond is maintained, and the possibility of voids eliminated.—*Dearborn Chemical Co., Chicago, Ill.*

Liquid Balance

By the use of the new Erdco automatic liquid balance, the flow measurement of any liquid can now be automatically determined by weight. The device operates without any interruption of the flow. By eliminating the possibility of human error, it obviates the necessity for time-consuming reruns.

The balance operates on the principle of measurement by weight and makes unnecessary all manual operation of valves, weight lifters, and switches. It measures the time required for a given quantity of liquid to flow, as determined by balancing against a calibrated weight. The determination is therefore independent of the physical properties and temperature of the liquid. The weighing section is installed in a polished hardwood cabinet, with removable glass door. The cabinet is 24 in. by 18 in. by 9 in.—*Engineering Research and Development Co Kinsdale, Illinois.*

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TRADE LITERATURE

Bus Washer—By descriptive text, photographic arrangements, and colored diagrams, this catalog gives various brush arrangements, layouts, piping, method of control, and general specifications for washing buses. An economy curve is presented to show that any company operating as few as 20 buses can save money by using this washing method. Sixteen pages. Entitled "Clean Buses Are Good Business."—*Whiting Corp., Harvey, Ill.*

Chemical Products—A pocket-size illustrated booklet briefly describing the wide range of plastics products, resin and insulating products, metallurgical products, and plastics compounds and resins that are manufactured. About 50 individual items are covered, together with their many industrial applications. Eighteen pages. Booklet No. CDP-576.—*General Electric Co., Chemical Dept., Pittsfield, Mass.*

Dial Scales—Six new 3-color technical bulletins, bound together in one manual, offer data, diagrams, selection advice, and practical application information on dial scales, including counting; bench; platform, both portable and dormant; and crane scales; and weigh-can installations for the dairy industry. Bulletin titled "Yale Load King Scales." Sixty-eight pages.—*Yale & Towne Mfg. Co., 4530 Tacony St., Philadelphia 24, Pa.*

Fluorescent Lighting—The What, Why, Where, and How of cold-cathode fluorescent lighting is attractively presented on the pages of this booklet which was designed specifically for engineers and architects. Installation photographs and eye-catching cartoons illustrate the principal points of the textual information. Bulletin titled "Cold Cathode Fluorescent Lighting Guide." Eight pages.—*Fluorescent Lighting Association, 501 Fifth Ave., New York 17, N. Y.*

Induction Motors and Generators—This booklet describes the various types of two-phase induction motors and induction generators designed specifically for high performance service applications. Motor performance curves and outline drawings of both motors and generators amplify the descriptive text. Six pages.—*Arma Corp., 254 36th St., Brooklyn 32, N. Y.*

Industrial Processing—A modern way to clean and cool gases, by use of Peabody scrubbers and coolers, is described in this compact folder. Capacity and construction, method, operating principle, and typical applications are but a few of the items presented. Diagrams and illustrations supplement the text. Bulletin No. H-203. Four pages.—*Peabody Engineering Corp., 580 Fifth Ave., New York 19, N. Y.*

Microscope—A folder describing the Wilder Toolmaker microscope points out the advantages of employing microscopic measuring for checking threads, angles, tapers, bevels, etc. Specifications and dimensions are included, as well as a table showing the co-ordinate measurements possible. Four pages.—*George Scherr Co., 200 Lafayette St., New York 12, N. Y.*

Notching Units—Independent, self-contained notching units for interchangeable use and reuse in unlimited set-ups in stamping presses and press brakes are described at length in this attractively illustrated three-color booklet. T-slotted set-ups, together with plates and accessories, are shown in operation. This edition includes illustrations of several special units capable of round-corner notching, deep-square notching, irregular-shaped notching, angle-iron notching, etc. Sixteen pages. Catalog N.—*Wales-Stribbitt Corp., North Tonawanda, N. Y.*

Permanent Magnet Subassemblies—This concise, illustrated booklet contains a description of permanent magnet subassemblies. The text explains how they eliminate assembly-line rejects, high cost of test equipment, bushing and chipping losses, etc. Among the types illustrated are the magnetic-focusing and Titan Valve subassembly, magnetron and cable clamp subassembly, a radar jammer tube, and a snap-action switch. Four pages. Bulletin No. CDM-16.—*General Electric Co., Metallurgy Div., Chemical Dept., Pittsfield, Mass.*

Pyrometer Controller—A bulletin presenting an electronic pyrometer controller describes the application of the instrument in proportioning the current input to electrically heated furnaces, ovens, plastic molding machines, salt pots, and other similar equipment to provide practically straight line control. Bulletin No. PB-1237.—*The Bristol Company, Waterbury 91, Conn.*

Rotameters—This loose-leaf catalog covers a full line of rotameters for flow-rate measurement and control, including the Full-View, Stain-Met, and Inductronic rotameters. The Sho-Rate rotameter for purge systems also is described, and capacity charts, data sheets, and dimension prints for each type of meter are included. Twenty-four pages.—*Brooks Rotameter Co., P.O. Box B-30648, Lansdale, Pa.*

Stainless-steel Equipment—Described in this bulletin are the facilities for designing and manufacturing stainless-steel custom-built equipment for industrial use. A number of illustrations show the type of finished equipment the company is capable of manufacturing to meet special requirements and specifications. Bulletin No. 51. Four pages.—*Jensen Machinery Co., Bloomfield, N. J.*

Switches—This illustrated catalog fully describes a complete line of snap-action switches, including bakelite-enclosed and open-blade types in a wide variety of shapes and sizes. For each there is a table of operating characteristics. Switches for use in special applications such as midjet, nut type, and circular assembly are included. Twenty pages. Titled "Rolling Spring Switches."—*Acro Electric Co., 1424 Superior Ave., Cleveland 14, Ohio.*

Synthetic Fabrics—Samples of both Nylon and Fiberglas fabrics are attached to the cover of this booklet which briefly outlines their many uses, advantages, and characteristics. Technical data for each fabric is provided in table form. Eight pages. Titled "New Synthetic Fabrics for Industry."—*The Duplan Corp., 512 Seventh Ave., New York 18, N. Y.*

BOOK REVIEWS

(Available books may be purchased through the GENERAL ELECTRIC REVIEW for domestic delivery; none sent on approval.)

Power System Stability: Vol. I—Elements of Stability Calculations

Edward W. Kimbark—John Wiley & Sons, Inc., New York. 1948. 365 pp. \$6.00.

Although there appears to be no lack of elementary texts on electrical machinery or on stationary networks, there exists only a scanty supply of introductory books on power systems involving both types of apparatus. The present book is planned to supply that need by being the first of three volumes covering the elements of power-system stability. In particular, this volume treats the simplified methods of stability calculations; a second will cover power circuit breakers and protective relays; and a concluding volume will introduce the more advanced methods of stability calculations.

The volume under review is devoted to methods of analysis of transient stability and to the evaluation of the principal factors affecting it. The procedures for the step-by-step calculation of swing curves and the accompanying repeated solution of networks are augmented by instructions for using the available a-c calculating boards. The alternative graphical method known as the equal-area criterion for stability and the attendant studies of fault-clearing time are also given in great detail. The effects of the type of faults on stability are reviewed with the aid of symmetrical components and sequence networks. The volume closes with detailed descriptions of typical stability studies on existing or projected power systems.

The volume is intended as a textbook for graduate students and practicing engineers, and as such it is amply illustrated by examples and references. (Answers to the numerous problems are not included, however.) The book fills a definite need and is to be highly recommended.

GABRIEL KRON

FM Transmission and Reception

John F. Rider and Seymour D. Uslan—John F. Rider, Publisher, Inc., New York. 1948. 415 pp. Cloth \$2.70; paper \$1.80.

This book includes a very complete treatment of all phases of FM: basic theory, transmission, reception, circuit design, and servicing. The material is presented in such a form that most of it can be understood by anyone with a high-school education, although the more complicated problems of receiver and transmitter design will, of course, be appreciated only by those who have some background in the radio field. There is very little mathematics used throughout the book, and most of the concepts of the modulation and the transmission and reception of radio waves are explained in simplified language and well illustrated with numerous diagrams and curves. In cases where a knowledge of mathematics is a prerequisite for the understanding of some phenomenon, the author does not attempt what would otherwise be an unsatisfactory explanation.

The techniques used in FM broadcasting and reception have been so varied and have changed so much during the past few years that most of the material describing these techniques is scattered throughout the current periodicals, so that it is difficult to gather complete information on any one phase of FM. This treatment of the subject,

however, goes a long way toward improving that situation. For example, almost all the presently used commercial FM transmitters are described in considerable detail, including the original Armstrong phase-modulation system, the General Electric phasitron system, the Westinghouse direct FM system, and at least half a dozen others.

There are sections on the transmission of FM signals, on antenna arrays, and on the differences in propagation characteristics at different frequencies. The different systems of detection used in the receiver are also described in considerable detail. Descriptions of the relatively new ratio detector, the "Fremodyne" detector, and the "locked oscillator" are also included, as well as the more conventional limiter-discriminator circuit.

The book is an up-to-date treatment of modern FM broadcasting principles and systems.

H. R. SUMMERHAYES, JR.

Corrosion Handbook

Herbert H. Uhlig, Editor-in-Chief; Sponsored by The Electrochemical Society, Inc.—John Wiley & Sons, Inc., New York. 1948. 1222 pp. \$12.00.

The Corrosion Handbook supplies a needed reference source for those who deal with corrosion problems. It is written by an imposing list of authoritatively qualified men who have summarized a wealth of data both from technical literature and from industrial experience and have condensed the material into a collection of short documented articles. The illustrations are clear and easy to understand.

A great part of the book contains factual material showing the corrosion behavior of metals and alloys in various environments: aqueous, atmospheric, high-temperature. Considerable space is given to the use of protective measures. Methods of corrosion testing are described in excellent detail. Enough theory is included to form a working basis for the study of corrosion problems. Surprisingly, several pages are devoted to the chemical resistance of wood, glass, plastics, etc. Just why is uncertain. At any rate, it is not probable that the individual looking for such information would go to a Corrosion Handbook for it, and it might well be omitted here.

In general, although no book can supply all the answers, this one should be a useful guide, because the corrosion data are quantitative and have been taken under well-defined conditions.

JOHN F. ECKEL

Progress in the Theory of the Physical Properties of Glass (Progress of Research in Holland)

J. M. Stevels—Elsevier Publishing Co., Inc., New York. 1948. 116 pp. \$2.00.

The Preface, written in February 1946, indicates that this book covers work performed and theories considered during the war years on the structure of glass through the study of certain physical properties, measured at room temperature only and correlated with chemical composition.

Four of the five sections of the book appeared originally in articles in the (English) Journal of the Society of Glass Technology

during 1946, now rearranged and generally abridged. These four sections are entitled I, General Introduction; II, The Density of Glass; III, The Electric Conductivity of Glass; V, The Molecular Refraction of Glass. The remaining section is IV, The Dielectric Losses of Glass.

Glasses made only of "glass formers" SiO_2 , B_2O_3 , P_2O_5 , and GeO_2 contain a predominantly large volume of oxygen ions. As these glass-forming oxides are combined, and as "glass-modifying" oxides (like Na_2O , CaO , PbO , and Al_2O_3) are added, the oxygen structure is modified, giving rise to changes in density. Exact measurements of density on numerous glasses are compared with the results obtained from calculations based upon theories of contraction and extension of volumes. The theories propounded are now highly controversial subjects, with vigorous proponents on both sides of the Atlantic.

Contrary to the statement in the preface, the sections on electric conductivity and dielectric losses deal with temperature dependence of these properties on changes in composition, particularly of Na_2O and K_2O . Theories are given to explain the "minima" found in the electrical measurements involving a change in alkali content. Some data on power factor are given for several glasses in the range 90 K to 450 K.

The many glass compositions and the many literature references are of great help to the theoretically minded person. The book suffers from lack of proofreading and deserves to be expanded and critically brought up to date.

LOUIS NAVIAS

Electricity (University Mathematical Texts Series)

Charles A. Coulson—Oliver and Boyd Ltd., Edinburgh and London; Interscience Publishers, Inc., New York. 1948. 266 pp. \$3.75.

The author has undertaken the formidable task of covering the many topics from electrostatics and permanent magnetism to alternating-current theory and Maxwell's Equations in one small volume. The result is an excellent, readable, semiadvanced survey of important principles.

Vector notation is used throughout, in keeping with Mr. Coulson's frank choice of a mathematical approach. Mathematical tools such as the Legendre polynomials and conformal transformation are freely employed. In contrast, however, the text itself is written in an easily understandable, down-to-earth manner.

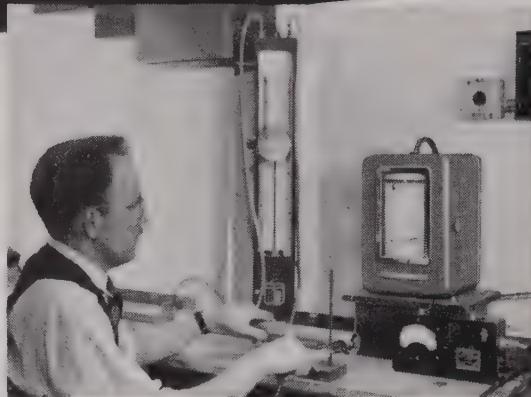
The topics are skillfully arranged to emphasize their fundamental interdependence. The first chapter briefly outlines the entire subject. Permanent magnetism follows the discussion of magnetic effects of currents and is related to it through atomic theory. Two chapters on potential fields treat magnetic and electric problems simultaneously.

The book is intended to be a test, primarily for students with a rather advanced mathematical background but with only an elementary knowledge of electricity. They should find it technically equivalent to many advanced physics texts, but much easier to understand. Engineering students

(Concluded on next page)

HIGH-SPEED RECORDING PROBLEMS SOLVED...

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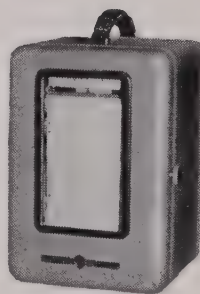


Further proof that the G-E Photoelectric Recorder can record anything that can be measured is found in the Illinois Testing Laboratory, Inc. Their engineers say, "The G-E Photoelectric Recorder provides a versatile, sensitive recording unit for temperature, light, and electrical phenomena." As shown above they are using it to record very low air velocities measured by their thermo-anemometer, an instrument for air circulation tests.

The extreme sensitivity and high-speed response of the photoelectric recorder make it ideally suited to this application, as well as for thermocouple response tests and resistance thermometry. It gives a complete recorded history of these operations.

The Illinois Testing Laboratory, Inc. is just one of the many users who have found the G-E Photoelectric Recorder useful in solving their recording problems. There are many other applications embracing the entire field of measurements, since the recorder can record anything that can be measured.

A wide range of sensitivities (which go as low as 1.0 microamperes for full scale deflection) and response speeds as high as 1/4 second are available in the photoelectric recorder. Basic elements are interchangeable so that one instrument can cover a number of ranges. It is also available as a potentiometer recorder. Write for Bulletin GEA-2394, or contact your nearest G-E sales office and let us help you with your application problems.



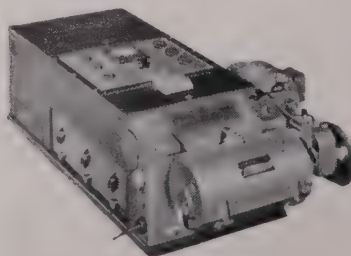
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BOOK REVIEWS (Continued)

are apt to have had more detailed course in the physical topics covered here before they have mastered the mathematics required to use the book. Many engineers will find it a concise, straightforward reference for basic electrical theory.

DEAN B. WHEELER

Powder Metallurgy—Its Physics and Production

Paul Schwarzkopf—The Macmillan Co. New York. 1947. 391 pp. \$8.00.

This book fills a long-felt need in a field which has developed rapidly in recent years. It brings together much of the published information, logically and accurately presents the facts, and discusses the various theoretical aspects involved in boundary grain size, and notch effects, compacting internal stresses, and diffusion.

The headings of the various chapters indicate the completeness with which the subject has been covered. The text reveals the familiarity and experience of the author with the subject as developed not only in this country but also abroad. The chapters on cemented carbides is quite complete and the whole treatment is accurate, well illustrated, and up-to-date. An excellent bibliography of some 600 references, segregated as they apply to each division, is a valuable addition to the book. There are four main divisions: Processing, Production, Theoretical Principles, and Future Developments. The book will be found most valuable to all who are interested in powder metallurgy, including engineers and executives who will find in it the answers, as far as they are known, to the questions of application, manufacture, and peculiar uses of this relatively recent method of producing metal parts.

There is an obvious error in the sintering temperature of copper, page 107 (given as 1500-1700 C). The sintering temperature of the aluminum-nickel-iron-cobalt permanent-magnet alloys, page 112, should be 1350-1425 C instead of 1200-1300 C, as given.

W. E. RUDE

Nuclear Forces, Part I

L. Rosenfeld—Interscience Publishers, Inc. New York. 1948. 205 pp. \$5.00.

This is the first of two volumes by one of the best-known Dutch theoretical physicists, now a professor at the University of Manchester. The main line of argument of the book is theoretical, but it is salted with critical discussions of experimental results and techniques. The point of view is that of the famous series by Bethe and Bacher in *Reviews of Modern Physics*, and the present work may be regarded as an effort to bring that classic up to date. This volume begins with a semiquantitative discussion of nuclear forces in relation to nuclear radii and mass defects, and the major portion of the book is devoted to a very detailed discussion of the neutron-proton system and of proton-proton scattering.

The subject of nuclear physics has developed so rapidly since the war that any comprehensive review is likely to be out-of-date by the time it gets into print. Dr. Rosenfeld's effort is no exception, but this does not detract seriously from its usefulness. An unfortunate feature of the book is that the bibliography and the index, plus a number of illustrations and tables referred to frequently in the text, have been relegated to the second volume, which is not yet available.

HARVEY BROOKS

LIBRARY NOTES

ON ARTICLES IN OTHER TECHNICAL JOURNALS

AIR COMPRESSORS

Axial-flow Compressors for Gas Turbines

A. I. Ponomareff—*ASME Trans.*, May 1948; v. 70, pp. 295-306.

Deals with the operating principles, characteristics, types, and other data pertaining to the axial-flow compressor.

BETA RAYS

Beta-ray Measurements and Units

M. Blau and J. E. Smith—*Nucleonics*, June 1948; v. 2, pp. 67-74.

The authors have developed an instrument, using a photomultiplier tube and standard radioactive source, for making beta-ray measurements in terms of a newly proposed unit.

BRAKES, EDDY-CURRENT

Thyatron Braking for Oil-drilling Rigs

Ralph L. Jaeschke—*Electronics*, Apr. 1948; v. 21, pp. 92-94.

Electronic equipment performs reliably as a source of direct current for eddy-current brakes.

CALCULATING INSTRUMENTS

Design of D-c Electronic Integrators

Granino A. Korn—*Electronics*, May 1948; v. 21, pp. 124-126.

Effects on the accuracy of integration of amplifier gain, capacitor leakage, input and output resistance are analyzed.

CAMERAS

New Three-color Camera

Jack H. Coote—*Soc. Motion Pict. Engrs. Jour.*, June 1948; v. 50, pp. 543-553.

Here is described a beam-splitter color camera which utilizes the principle of a single-reflection prism block to expose three films in the combination of "bipack and one."

CORROSION

Fluorine Corrosion

W. R. Myers and W. B. DeLong—*Chem. Engng. Prog.*, May 1948; v. 44, pp. 359-362.

Description of high-temperature attacks on metals by fluorine and hydrogen fluoride; behavior of insulated steel parts in fluorine cells.

DIFFERENTIAL EQUATIONS

Approximate Solution of Linear Differential Equations

Marion C. Gray and S. A. Schelkunoff—*Bell System Tech. Jour.*, Apr. 1948; v. 27, pp. 350-364.

A note to illustrate the accuracy of the "wave-perturbation" method for the approximate solution of linear differential equations.

DUST

Photometric Investigation of Dust

Domina Eberle Spencer and Selma Malkiel—*Franklin Inst. Jour.*, May 1948; v. 245, pp. 389-402.

Consideration of the quantitative knowledge of the effect of dust as of practical importance in the design of luminaires and in the prediction of the performance of lighting systems.

ELECTRIC-CURRENT RECTIFIERS

Rectifier Resistance Laws; Analysis of Nonlinear Transmission Circuits

D. G. Tucker—*Wireless Engr.*, Apr. 1948; v. 25, pp. 117-128.

Includes resistivity vs. temperature, voltage, current, etc., for copper oxide, selenium, silicon, germanium crystals, and diodes.

ELECTRICITY APPLICATIONS—RAILWAY CARS

Power Networks for Passenger Trains

Ry. Age, May 8, 1948; v. 124, pp. 903-905.

A motor company develops alternating-current diesel-engine-generator sets for mounting on cars which can be "train-lined" to insure power continuity.

FAULTS, ELECTRIC

New Method for the Location of Faults in Overhead Transmission Lines by Means of Impulse Tests

S. Margoules and P. Fourmarier—*Engrs. Digest (Am. Ed.)*, May/June 1948; v. 5, pp. 177-179.

Abstract translation from a Belgian publication. Serial.

FOUNDRY PRACTICE

Centrifugal and Precision Steel Castings for Aircraft

J. F. B. Jackson—*Engng.*, May 21, 1948; v. 165, pp. 481-484.

Methods of production. Includes consideration of castings for gas turbines.

FURNACES, INDUSTRIAL

Heat-processing Easily Oxidized Metals

F. C. Kelley—*Iron Age*, May 20, 1948; v. 161, pp. 84-89.

A technique for purifying and applying hydrogen atmosphere for furnace-brazing, bright-annealing, and sintering metals easily oxidized in reducing atmosphere furnaces. The author describes the construction of several laboratory and commercial units.

HEAT TREATMENT

Furnaces and Fuels for Heat-processing Metals

Floyd E. Harris—*Steel*, May 10, 1948; v. 122, pp. 90-94.

Controlling factors involved in attacking heating problems and in determining atmospheric applications and surface effects are analyzed.

HEATING, RADIANT

Ground-temperature Distribution with a Floor-panel Heating System

A. B. Algren—*Heat. Piping & Air Cond.*, May 1948; v. 20, pp. 111-119.

Describes the construction and test equipment of a basementless research residence heated by a warm-air floor-panel heating system.

JIGS AND FIXTURES

Work-holding Fixtures for Production Broaching

Prod. Engng. & Man., May 1948; v. 21, pp. 56-59.

LIQUIDS

Correlating Surface Tensions of Liquids: A New Nomograph

Donald F. Othmer and others—*Ind. & Engng. Chem.*, May 1948; v. 40, pp. 886-889.

Surface tensions of a liquid at various temperatures have been correlated to give

straight-line plots on logarithmic paper against the surface tensions of a reference liquid at constant values of the critical difference temperature.

MACHINE DESIGN

Design Stress Factors

Joseph P. Vidosic—*Jour. Engng. Educ.*, May 1948; v. 38, pp. 653-658.

MACHINE-SHOP PRACTICE

Machining Copper and Its Alloys

Joseph J. McGuinness—*Am. Mach.*, May 6, 1948; v. 92, pp. 101-112.

Latest available data on machining all the commonly used copper and copper-base alloys are here assembled in one compact report.

MAGNETISM

Magnetostriction Generators

J. A. Osborn—*Elec. Engng.*, June 1948; v. 67, pp. 571-578.

A survey of fundamental magnetostriction phenomena and their application to the conversion of mechanical to electric energy, or conversely. Includes consideration of the transducer.

MEASURING INSTRUMENTS

Instantaneous Temperature-measurement of Fast-moving Objects

Instrumentation, No. 3, 1948; v. 3, pp. 25-26.

Describes the Optimatic, an electronically operated optical pyrometer for surface temperatures of 850 to 3,000 F on fast-moving objects.

Pneumatic Method for Measuring High-temperature Gases

David William Moore, Jr.—*Aero. Engng. Rev.*, May 1948; v. 7, pp. 30-34.

Instruments and methods for measuring temperatures encountered in jet and rocket propulsion.

Portable Electronic Chronometer

G. T. Baker—*Jour. Sci. Instr.*, June 1948; v. 25, pp. 194-198.

Gives directly the operating or release times of relays and the like, measured to either "make" or "break" contacts. Circuit transients and contact-difference times can also be measured.

METAL PROTECTION

Importance of Controlled Humidity in Long-time Preservation

George C. Wells—*Am. Soc. Nav. Engrs. Jour.*, May 1948; v. 60, pp. 127-138.

Maintenance of an atmosphere having comparatively low relative humidity for the preservation of interiors of ships which are retained as a part of the Navy but in inactive status.

METALS—EMBRITTEMENT

Hydrogen Attack on Carbon Steels

T. C. Evans—*Mech. Engng.*, May 1948; v. 70, pp. 414-416.

(Concluded on next page)

MEMO TO PRESIDENTS WHO WATCHED THE BAND GO BY!

HERE'S ONE parade that isn't "all over but the shouting" after the band has passed. It's the Payroll Savings Plan for the regular purchase of U.S. Security Bonds by employees.

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LIBRARY NOTES (Continued)

OSCILLATIONS

Self-excited Mechanical Oscillations

N. Minorsky—*Jour. App. Physics*, Apr. 1948; v. 19, pp. 332-338.

Deals with certain self-excited oscillations observed in a mechanical system possessing a retarded action.

PLASTICITY

Plasticity for the Aero-dynamicist

William Prager—*Jour. Aero. Sci.*, May 1948; v. 15, pp. 253-262.

A survey of the classical theory of plasticity as applied to problems of plane-plastic flow.

POWER PLANTS

Load Research Methods

Elec. Wld., May 22, 1948; v. 129, pp. 123-126.

Purposes of studies; sampling procedures; assembly of information to put study reports on comparable bases; compilation practices.

PRECISION INVESTMENT CASTING

Critical Survey of Investment Casting

Rawson L. Wood and Davidlee Von Ludwig—*Iron Age*, May 6, 1948; v. 161, pp. 72-78.

Presents, in concise form, information and data necessary to intelligently appraise the potentialities of investment casting as a means of reducing costs or improving performance. Serial.

RADIO ENGINEERING

Analysis of the Intermodulation Method of Distortion Measurement

W. J. Warren and W. R. Hewlett—*Inst. Radio Engrs. Proc.*, Apr. 1948; v. 36, pp. 457-466.

Results obtained by the use of the intermodulation method are compared with those obtained by the harmonic-measurement method.

RADIOGRAPHY

Detection of Cracks by X- Rays and Gamma Rays

C. Croxson—*Electronic Engng.*, Apr. 1948; v. 20, pp. 106-111.

REFRIGERATING ENGINEERING

Refrigerating Capacity of Two-component Systems

Frank T. Gucker, Jr. and Glenn A. Marsh—*Ind. & Engng. Chem.*, May 1948; v. 40, pp. 908-915.

The properties of glycerol-water and propylene glycol-water for use in quick freezing.

REGULATORS

Tensorial Analysis of Control Systems

Gabriel Kron—*Jour. App. Mech.*, June 1948; v. 15, pp. 107-124.

The theory of such a method of analysis is explained.

SOUND RECORDING AND REPRODUCTION

Magnetic Recording Media as Components in Product Design

Alex E. Javitz—*Elec. Mfg.*, May 1948; v. 41, pp. 82-87, 139-141.

There is far more to magnetic recording than speech and music recorders for home

use. Test and laboratory instruments, computing machines, control devices, sound-on-film, and a multitude of other design projects are being intensely investigated.

TEMPERATURES

Simulation of High Air Temperatures by Hydrogen Admixtures

Boris N. Cole—*Engng.*, May 28, 1948; v. 165, p. 508.

The theory of using hydrogen-air or hydrogen-nitrogen mixtures for simulating high-temperature air in experiments where work with air itself is impracticable. For applications in gas-flow research, as with compressors and gas turbines.

UNIVERSAL JOINTS

Constant Velocity Joints; How and Why They Operate as They Do

H. H. Mabie—*Mach. Design*, May 1948; v. 20, pp. 101-105.

The construction and performance of several types of universal joints designed to obviate speed variations. Includes consideration of the Cardan, Bendix-Weiss, Rzeppa, and Tracta joints.

WELDING—POSITIONERS

Jigs and Fixtures Facilitate Economic Mass Welding

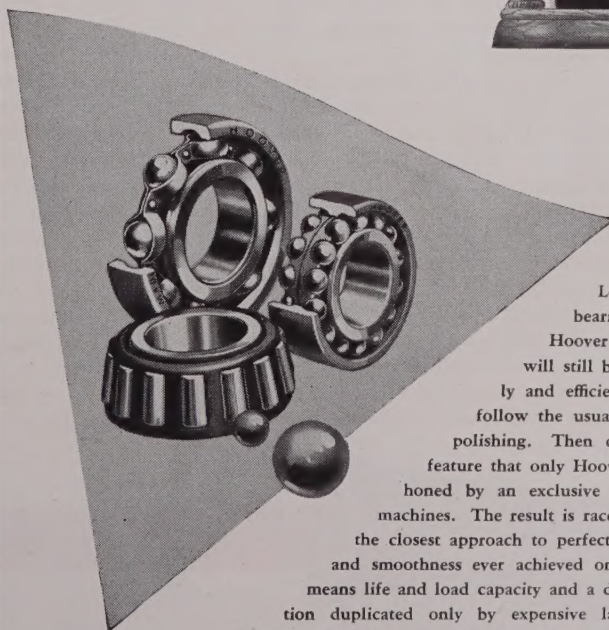
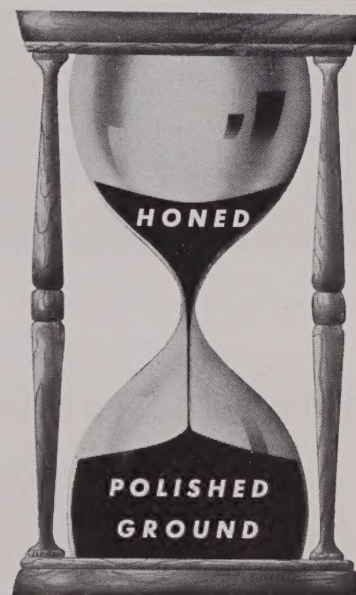
O. L. Dubie—*Steel*, May 3, 1948; v. 122, pp. 90-93.

Cites actual examples of how the use of positioners and fitting and holding devices saves one metal fabricator time and money.

HONED RACEWAYS

give HOOVER ball bearings

30% longer life



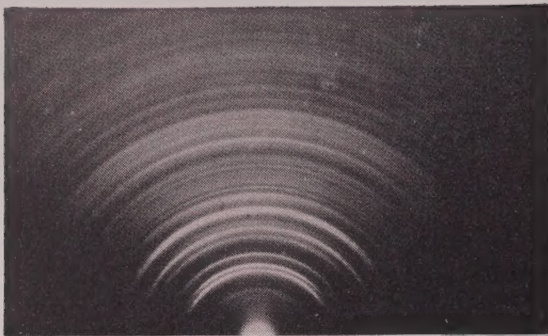
Long after the average ball bearing has been replaced, Hoover Honed Raceway Bearings will still be operating quietly, smoothly and efficiently. Hoover Ball Bearings follow the usual processes of grinding and polishing. Then comes a third step, a plus feature that only Hoover offers. The bearings are honed by an exclusive method on special Hoover machines. The result is raceway curvatures representing the closest approach to perfection in uniformity, precision and smoothness ever achieved on a commercial basis. This means life and load capacity and a degree of quietness of operation duplicated only by expensive laboratory samples. Specify Hoover Ball Bearings and secure the plus values of honed raceways.

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Electron diffraction pattern of iron oxide as it occurs on steel surfaces subjected to high temperatures.



This represents the orientation of graphite after it has been rubbed between two steel surfaces.



How Electron Diffraction Instrument Helps NACA Search for High-speed and High-temperature Lubricants

Among the many problems presented by jet engines, lubrication is high on the priority list. Ordinary lubricants are not adequate for the high-temperature and high-speed conditions. New and improved lubricants are necessary.

The National Advisory Committee for Aeronautics in Cleveland began a study of this problem three years ago. And General Electric's Electron Diffraction Instrument is playing an important role.

FIRST, an investigation is made of superficial films on low and high-temperature steels, for use in bearings, gears and cylinder walls. By studying diffraction patterns of the steel surface, NACA engineers determine the reaction of a specific lubricant to that surface. In a five-second exposure, the Electron Diffraction Instrument detects chemical changes on the surfaces.

SECOND, a study is made of natural films which may emanate from steel which has not been subjected to any form of testing and is without the benefit of artificially applied chemicals. Identification is made with the Diffraction Instrument.

THIRD, film materials formed on jet bearings during typical operation are identified by the Diffraction Instrument.

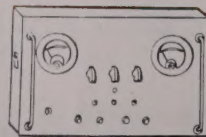
This is just one example of the instrument's many research and testing applications. It is being employed to study catalysts, friction and wear, corrosion, surface deposits, graphites, pigments for paints, inks, dyes, and in metallurgical investigations.

G-E ENGINEERS have helped solve thousands of problems for industry. Frequently, the result has been a new testing and measuring equipment . . . equipment that today is saving time and money.

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General Electric testing and measuring equipment for nearly every industrial process



Chemical Analysis



Color and Light



Vacuum and Pressure